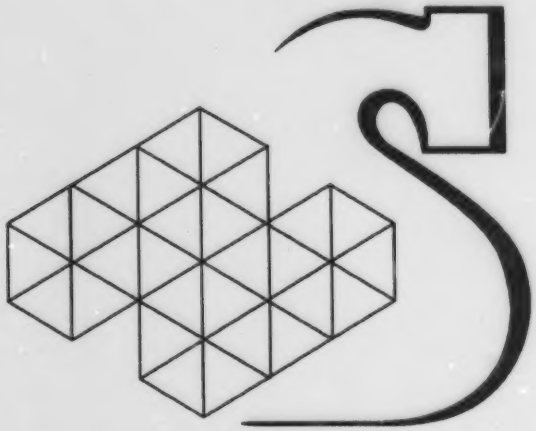

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REVIEW OF THE TADMUS DECISION SUPPORT SYSTEM

By D.J. Bryant

April 2001

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Review of the TADMUS Decision Support System

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Abstract

This report describes a review of the U.S. Navy TADMUS DSS with respect to the goal and mental representation requirements of the Operations Room Officer (ORO) position of the HALIFAX class frigate. The review was conducted in a one-day session on February 12, 2001, using TADMUS DSS simulation software provided by DCIEM. The goal and mental representation frameworks were based on an analysis of results of a Cognitive Task Analysis (CTA) for the ORO position by Matthews, Webb, and Bryant (1999). The goal of the review was to identify which dimensions of ORO mental representations and which ORO goals are supported by the U.S. Navy TADMUS DSS and which dimensions are not supported. The review indicated that the TADMUS DSS supported only some ORO goals and generally did not support as abstract a level of mental representation as needed by OROs.

SYNTHÈSE

Le présent rapport traite de l'examen du système de soutien décisionnel (SSD) TADMUS de la U.S. Navy en ce qui concerne l'objectif et les besoins en représentation mentale du poste d'officier de la salle des opérations (OSO) de la frégate de classe *Halifax*. Le logiciel de simulation du SSD TADMUS fourni par l'IMED a été examiné au cours d'une séance d'une journée, le 12 février 2001. Les cadres de référence pour l'objectif et la représentation mentale étaient fondés sur les résultats de l'Analyse cognitive des tâches (ACT) du poste d'OSO par Matthews, Webb et Bryant (1999). Le but de l'examen était de déterminer quelles dimensions des représentations mentales de l'OSO et lesquels de ses objectifs sont soutenus par le SSD TADMUS de la U.S. Navy et quelles dimensions ne le sont pas. L'examen a révélé que le SSD TADMUS ne soutenait que quelques objectifs des OSO et, en général, pas un niveau de représentation mentale suffisamment abstrait pour leurs besoins.

Executive Summary

Matthews, Webb, and Bryant (1999) performed a Cognitive Task Analysis (CTA) for the Operations Room Officer (ORO) position of the HALIFAX class frigate. Based on the results, they developed frameworks to describe ORO goals and mental representations, which can serve as a means of identifying ORO information needs. The current project was undertaken to review the information content and organization of the TADMUS DSS with respect to the dimensional framework of ORO mental representations and goals created by Matthews et al. (1999). The goal was to identify which dimensions of ORO mental representations and which ORO goals are supported by the U.S. Navy TADMUS DSS and which dimensions are not supported.

The U.S. Navy has developed a DSS as part of their TADMUS (Tactical Decision Making Under Stress) project. The goals of this review were to make a first identification of what elements in the TADMUS DSS might be reusable in the HALIFAX context based on the results of the work domain model developed as part of the project (Burns & Bryant, 2000b), to determine where the DSS is likely to be deficient, and to suggest viable means for addressing these deficiencies.

Based on their CTA results, Matthews et al. (1999) identified ORO goals and divided them into three broad aspects of the ORO role: coming on watch goals, background goals, and foreground goals. Another major finding of the CTA was OROs' widespread use of various forms of mental representations. Matthews et al. (1999) developed a categorization scheme based on three dimensions: level of abstraction, level of focus, and domain of interest.

As part of the review, we identified links between DSS elements to compare the organization of the DSS to the goal and mental representation frameworks of Matthews et al. (1999). The author inspected each module of the TADMUS DSS, reviewing all screens and components. Using a datasheet, the author recorded all elements of the TADMUS DSS in relation to the ORO mental representation dimensions and goals. This effort was facilitated by performing a series of task simulations by working through a representative set of ORO tasks (primarily air and surface threat detection and response). The review was conducted in a one-day session on February 12, 2001, using TADMUS DSS simulation software provided by DCIEM.

The results of the review can be summarized as follows:

- The TADMUS DSS provided support for only some classes of ORO goals, namely those associated with the ORO's picture building and managing the response to a contact.
- A review of the mental representation requirements of ORO goals revealed that the TADMUS DSS generally supports mental representations that are less abstract than those needed by OROs. Many ORO goals, especially background and coming on watch goals, require mental models that integrate data with mission goals, ROE restrictions, and other conceptual issues. The TADMUS DSS, however, focuses on the immediate tactical situation and presents information that can help the operator build an abstract picture - but a picture that does not truly provide an integrated model of the situation.
- The TADMUS DSS tends to support representations with a specific, rather than global, domain of interest because it presents detailed analysis of only one contact at a time. The system does not feature any analysis of the relations among multiple contacts. Nevertheless, an ORO needs to create a representation based on just that kind of relational knowledge in order to evaluate relative threats, priorities, and patterns that could suggest contacts' intent or possible COAs.

- The information requirements suggested by the ORO goal and mental representation frameworks can be mapped onto information support provided by the TADMUS DSS in Functional Information Profile (FIP) diagrams. These diagrams indicate areas of the work domain where OROs have information needs not met by the TADMUS DSS.

The TADMUS DSS offers a wide range of features to aid identification and classification of contacts and response to contacts. The review, however, suggested that design of a DSS and workstation for the ORO position of the HALIFAX class would benefit from consideration of the goal and mental representation structures of OROs. By relating design concepts to goal and mental representation requirements, designers can better evaluate the appropriateness and value of those design concepts to supporting ORO performance.

The results of the review are subject to several limitations. First, the review was conducted over the course of one day and the TADMUS DSS simulation software had only a few scenarios with which to explore its functionality. It is not clear that the simulation reviewed provides a comprehensive overview of the TADMUS DSS concept. Second, the simulation was "stand-alone" and provided no opportunity to examine how the workstation functioned as part of a system of workstations. Third, the TADMUS DSS was developed by and for the United States Navy, which has different strategic, tactical, and operational priorities than the Canadian Navy. This limitation must be dealt with by identifying key departures of Canadian concerns from those of the United States and incorporating these in any future review of TADMUS systems. In particular, the TADMUS DSS was developed in the context of the U.S. Navy's Aegis class, which serves primarily an anti-air role. It is not clear based on the simulation reviewed for this report to what extent the TADMUS DSS supports subsurface picture building. Given that the HALIFAX class is a multi-purpose vessel, it will be important to support situation assessment in all warfare areas, air, surface, and subsurface.

RÉSUMÉ

Matthews, Webb et Bryant (1999) ont mené une Analyse cognitive des tâches (ACT) à l'égard du poste d'officier de la salle des opérations de la frégate de classe *Halifax*. À l'aide des résultats de leur analyse, les auteurs ont établi des cadres de référence pour décrire les objectifs et les représentations mentales des OSO qui peuvent servir à indiquer les besoins en information de ceux-ci. Le présent projet a été entrepris en vue d'examiner le contenu d'information et l'organisation du SSD TADMUS à la lumière du cadre de référence dimensionnel des représentations mentales et des objectifs d'un OSO créé par Matthews et coll. (1999). Le but de cette étude était de déterminer les dimensions des représentations mentales et les objectifs de l'OSO qui sont soutenus par le SSD TADMUS de la U.S. Navy et ceux qui ne le sont pas.

La U.S. Navy a élaboré un SSD à l'intérieur du projet TADMUS (Tactical Decision Making Under Stress). Les buts de cet examen étaient d'identifier les éléments du SSD TADMUS qui seraient utilisables dans le context de la classe *Halifax*, en se basant sur les résultats du modèle de « domaines de travail », élaboré dans le cadre du projet (Burns et Bryant, 2000b), de déterminer où le SSD risque d'être inéfficient et de suggérer des moyens viables pour remédier à ces déficiences.

En se basant sur les résultats de l'ACT, Matthews et coll. (1999) ont établi les objectifs d'un OSO et les ont divisés en trois grandes catégories : les objectifs de service, les objectifs d'arrière plan et les objectifs d'avant-plan. Une autre importante découverte de l'ACT a été l'utilisation étendue, par l'OSO, de diverses formes de représentations mentales. Matthews et coll. (1999) ont élaboré un schéma de classement faisant état de trois dimensions : niveau d'abstraction, niveau de focalisation, et domaine d'intérêt.

Au cours de cet examen, nous avons défini les liens entre les éléments du SSD afin de comparer son organisation avec les cadres de référence des objectifs et représentations mentales de Matthews et coll. (1999). L'auteur a inspecté chaque module du SSD TADMUS, examinant toutes les grilles et composantes. À l'aide d'une fiche technique, l'auteur a consigné tous les éléments du SSD TADMUS ayant rapport aux objectifs et dimensions de la représentation mentale des OSO. Ce travail a été facilité par l'exécution d'une série de simulations de tâches-type de l'OSO (essentiellement la détection de menaces aériennes et de surface et la réaction subséquente). L'examen à l'aide du logiciel de simulation du SSD TADMUS fourni par l'IMED a eu lieu au cours d'une séance d'une journée, le 12 février 2001.

Les résultats de l'examen se résument comme suit :

- Le SSD TADMUS n'a soutenu que certaines classes d'objectifs des OSO, notamment celles associées à la construction d'images et à la réaction à un contact.
- L'examen des besoins en représentation mentale relativement aux objectifs des OSO a révélé que les représentations soutenues par le SSD TADMUS sont en général moins abstraites que celles dont ont besoin les OSO. Beaucoup des objectifs des OSO, en particulier ceux d'arrière-plan et de service, nécessitent des modèles mentaux capables d'intégrer des données aux objectifs des missions, aux restrictions relatives aux RDE, et à d'autres enjeux conceptuels. Le SSD TADMUS, cependant, met l'accent sur la situation tactique immédiate et présente des informations qui peuvent aider l'opérateur à construire une image abstraite, mais une image qui ne fournit pas vraiment un modèle intégré de la situation.

- Le SSD TADMUS tend à soutenir des représentations avec un domaine d'intérêt spécifique plutôt que global, parce qu'il présente l'analyse détaillée d'un seul contact à la fois. Ce système ne comporte aucune fonction d'analyse des relations entre contacts multiples. Un OSO doit, toutefois, créer des représentations fondées justement sur ce genre de connaissances relationnelles afin d'évaluer des menaces, des priorités et des comportements qui pourraient donner des indices sur les intentions et plans d'action éventuels du contact.
- Les besoins en information proposés par les cadres de référence des objectifs et des représentations mentales de l'OSO peuvent être transférés sur support informatique fourni par le SSD TADMUS sous forme de diagrammes du profil fonctionnel de l'information. Ces diagrammes indiquent les champs du domaine de travail dans lesquels l'OSO a des besoins d'information qui ne sont pas satisfait par le SSD TADMUS.

Le SSD TADMUS offre une vaste gamme de caractéristiques qui aident à identifier et classer les contacts et la réaction à ces contacts. Cependant, l'examen a indiqué, pour concevoir un SSD et un poste de travail pour le poste d'OSO de la classe *Halifax* il serait utile de tenir compte de la structure des représentations mentales et des objectifs des OSO. En reliant les principes conceptuels aux besoins en représentation mentale et aux objectifs, les concepteurs sont mieux en mesure d'évaluer la pertinence de ces mêmes principes et leur capacité à soutenir le rendement des OSO.

Les résultats de l'examen sont assujetties à plusieurs restrictions. D'abord, l'examen n'a durée qu'une journée et le logiciel du SSD TADMUS ne disposait que de quelques scénarios permettant d'explorer ses fonctions. Il n'est pas sûr que la simulation examinée a donné une vue d'ensemble exhaustive du concept du SSD TADMUS. Ensuite, la simulation était isolée et n'a pas fourni l'occasion de voir comment le poste de travail fonctionne quand il est intégré à un système de postes de travail. Enfin, le SSD TADMUS a été développé par et pour la U.S. Navy, qui a des priorités stratégiques, tactiques et opérationnelles différentes de la marine du Canada. Ce problème doit être résolu par l'identification des différences les plus importantes entre les préoccupations du Canada et des États-Unis et par leur incorporation dans tout examen futur des systèmes TADMUS. Le SSD TADMUS, notamment, a été développé dans le contexte de la classe *Aegis* de la U.S. Navy, qui joue avant tout un rôle antiaérien. Il ne ressort pas clairement de la simulation examinée pour le présent rapport dans quelle mesure le SSD TADMUS soutient la construction d'images sous-marines. Étant donné que le navire de classe *Halifax* est un navire polyvalent, il serait important de pouvoir soutenir des évaluations de situation dans toutes les zones de guerre, aériennes, de surface, et sous-marines.

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1 Introduction

1.1 Background

Bryant and Burns (2000) performed a work domain review of the TADMUS (Tactical Decision Making Under Stress) Decision Support System (DSS). The TADMUS DSS was compared to the work domain model developed in by Burns and Bryant (2000a, 2000b) to determine the extent to which the information content and organization of the TADMUS DSS corresponded to that of the work domain model. The review determined that the TADMUS DSS corresponded to limited aspects of the work domain model. The review also suggested that several elements of the work domain could be added to the TADMUS DSS.

Matthews, Webb, and Bryant (1999) performed a Cognitive Task Analysis (CTA) for the Operations Room Officer (ORO) position of the HALIFAX class frigate. The purpose of the CTA was to better understand cognitive aspects of Command and Control (C2) in the Operations Room (OR) as a prelude to preparing evaluation measures and methods to assess future Command and Control support systems. One observation was that ORO activities are goal-directed and that these goals could be identified and recorded. A second major finding of the CTA was that OROs employ a variety of mental pictures and models to achieve their cognitive goals. Matthews et al. (1999) developed a categorization framework by which ORO mental representations were categorized along three dimensions or continua, which may vary in their permutations or combinations for any particular representation. These dimensions are: *level of abstraction* (i.e., a concrete image vs. an symbolized model vs. an abstract schema), *level of focus* (i.e., "ranged" in or out, the ship in isolation vs. the TG as a whole, immediate vs. future time frame) and *domains of interest* (i.e., warfare and resource areas vs. an overall picture).

The framework developed by Matthews et al. (1999) can serve as another means of identifying ORO information needs. Consequently, it can be used to review a system such as the TADMUS DSS to determine that system's information content and organization. Doing so would create a description of the TADMUS DSS information content and organization for comparison with the description created with respect to the work domain review of Bryant and Burns (2000).

1.2 Purpose

The objectives of this project are to:

1. Review the information content and organization of the TADMUS DSS with respect to the dimensional framework of ORO mental representations and goals created by Matthews et al. (1999),
2. Identify which dimensions of ORO mental representations and which ORO goals are supported by the TADMUS DSS and which dimensions are not supported,
3. Identify potential deficiencies of the TADMUS DSS with respect to the dimensional framework of ORO mental representations created by Matthews et al. (1999).

1.3 Acronyms

2D	Two Dimensional	OR	Operations Room
C2	Command and Control	ORO	Operations Room Officer
CCS	Combat Control System	ORS	Operations Room Supervisor
CIC	Combat Information Center	ROE	Rules of Engagement
CO	Commanding Officer	SME	Subject Matter Expert
COA	Course of Action	TADMUS	Tactical Decision Making Under Stress
CRO	(Mini) Character Read Out	TAO	Tactical Action Officer
CSE	Combat Systems Engineer	TG	Task Group
CTA	Cognitive Task Analysis	U.S.	United States (of America)
DND	Department of National Defence	USS	United States Ship
DSS	Decision Support System	WD	Warfare Director
FIP	Functional Information Profile	WDA	Work Domain Analysis
IFF	Interrogate Friend or Foe		

2 Cognitive Task Analysis of the ORO Position

Matthews et al. (1999) performed a cognitive task analysis (CTA) of the ORO function in the HALIFAX class aimed at acquiring knowledge concerning ORO information needs, decision making, and strategies used to gather this information and make decisions during various phases of operations. A second goal of the CTA was to identify some future research priorities in Halifax class OR C2 operations. Through the CTA we have been able to identify a number factors that affect ORO and, by implication, OR performance, and which will require greater analysis and/or understanding in order to provide future system design guidance.

2.1 Method

The major steps in the CTA are listed in Table 2.1. Eight OROs were used as SME interviewees, four from the West Coast and four from the East Coast. SMEs had at least six months experience in a HALIFAX class vessel since completing their qualifying course.

Cognitive Task Analysis Steps	
1	Acquisition of domain knowledge by the CTA team
2.	Development of representative scenarios (context and activity sequence) based upon mission analysis plus observation and interviews with experienced OROs
3.	Stepping ORO interviewees through the sequences of events that comprise the scenarios
4.	Identifying ORO goals and related decisions and tasks
5.	Identifying the information needs to support critical decisions and tasks
6.	Identifying critical incidents, errors or other problems for ORO's based on interviewees' operational, exercise, or simulation experience when pursuing such goals

Table 2.1 - Cognitive Task Analysis Procedure

The CTA involved structured interviews based on a standardized scenario, with probe questions to elicit different information or cognitive requirements. The scenario stepped ORO interviewees through a series of threat events for a HALIFAX class vessel operating in a Task Group in a hostile littoral setting. This setting also featured day-to-day activity (commercial air lane, fishing vessels, oil platforms with helicopter traffic) to be monitored, from which emerged friendly, neutral, and hostile contacts. Interviewees were asked to identify their information needs in terms of key variables underlying Command and Control: Situation Awareness, Communication, Decision-Making and Mental Workload, which a previous study had identified as key areas of operator performance. They were also asked to identify the goals they had in mind, critical incidents, errors they had experienced or seen other ORO's produce, particular difficulties they faced in trying to achieve a goal and expert-novice differences, and workload levels.

2.2 Validation

Matthews and Webb (2000) conducted a validation of the CTA results to determine their completeness and accuracy. The validation was conducted by reviewing the CTA scenario and results with four OROs who had not participated in the original CTA. In general, the results of the

validation study supported the CTA, indicating the CTA results were largely accurate and generalizable. The validation study did, however, raise several issues leading to minor revisions of the analyses performed on the CTA data. Discussion of these analyses will reflect those changes.

2.3 Analyses

2.3.1 Goal analysis

Data analysis began with the observation that ORO C2-related behaviours, information processing, and actions are goal directed. Thus, the first step of the analysis was to determine ORO goals and then look at how the goals are accomplished, what information is required to support meeting the goal and what critical decisions are made. Matthews et al. (1999) sought to identify intermediate, generic goals that serve the achievement of broader goals. In particular, they recorded what OROs defined as major goals and important areas by which the system performance could be evaluated. They also focussed on analysing intermediate-level goals that serve a variety of mission related tasks. An example of such a goal is "*manage the OR team*". Such activities occur in most operational contexts.

An important background insight to the following is that ORO interviewees repeatedly emphasized that the role of the ORO was to maintain awareness of the "big picture" and to manage individual threat responses using OR team resources through the warfare directors rather than take over the response to individual threats. The ORO would only become involved in detailed threat response in the event that one or other warfare director was unable to cope satisfactorily. Furthermore, in the event of the ship coming to Action Stations, additional resources in the form of off-watch OR teams would arrive in the OR and come under the direction of the on-watch ORO. Matthews et al. (1999) divided ORO goals into three broad aspects of the ORO role:

- **Coming on watch tasks:** These goals / tasks represent the need of the ORO to update him or herself in all aspects of OR operation and awareness of the tactical and strategic situation for the mission.
- **Background tasks:** Background tasks are primarily those associated with the ORO's responsibility to manage the general preparedness of the OR to meet any threat and must be performed throughout the watch.
- **Foreground tasks:** These goals / tasks start once a specific threat is detected and tend to be initiated once pre-determined criteria or trip points require the pertinent warfare director to report to the ORO.

These categories are not necessarily mutually exclusive, as a particular goal may apply to some extent in more than one context. In particular, the validation study (Matthews & Webb, 2000) indicated that the distinction between background and foreground (threat-related) activities is often indistinct. The three categories of ORO goals will be used here only as a means of relating the TADMUS DSS to the original ORO CTA results. Table 2.2 contains the ORO goals identified by Matthews et al. (1999). The wording of goals has been changed to reflect insights gained from the validation study.

[redacted]
1 - Visualize external environment for the start of the watch
2 - Update own knowledge for coming watch from text messages
3 - Establish schedule of anticipated events for watch
4 - Update understanding of threats
5 - Establish current activity levels and work focus among OR team(s)
6 - Establish required action items during watch
7 - Review OR system performance (sensors, etc.) and rectify / work around
8 - Comprehend items in CO's order book
9 - Comprehend briefing from outgoing ORO
10 - Optimize own CCS
11 - Focus OR team on issues for coming watch
12 - Establish command presence
13 - Review pertinent pre-plans, procedures, and ROE for coming watch
Background Goals
1 - Monitor and manage the OR team
2 - Manage information from all sources coming into ORO position (speech, text, other)
3 - Monitor and manage OR equipment capability
4 - Build, monitor, and maintain awareness of pertinent surface environment
5 - Build, monitor, and maintain awareness of pertinent air environment
6 - Build, monitor, and maintain awareness of pertinent sub-surface environment
7 - Build, monitor, and maintain awareness of integrated environment from above
8 - Switch attention between different tasks and re-acquire awareness quickly
9 - Maintain awareness of ORO's authority to act
10 - Check outgoing message traffic (text, voice)
Foreground (Threat-Related) Goals
1- Integrate new contact information with own global awareness picture
2 - Ensure OR prepares quick first response, broad plan for worst case
3 - Optimize work among OR team(s)
4 –Optimize information flow within and outside OR
5 - Maximize number of information sources concerning contact
6 - Optimize data quality for each information source
7 - Establish communication with contact to resolve identity and intentions
8 - Conduct warnings in accordance with TG tasking
9 - Ensure contact classified correctly
10 - Ensure OR detects missile (etc.) firing and establish firm track
11- Ensure detailed and viable tactical plan prepared
12 - Check warfare directors (WD) plan
13 - Make CO aware of all relevant components of the plan. Get feedback from CO
14 - Ensure all OR team aware of plan. Emphasize key points
15 - Supervise execution of plan by OR team
16 –Ensure standard procedures completed correctly (ZIPPO, etc.)
17 - Maintain own global awareness during threat response
18 - Back up Warfare Directors (WD) as required
19 - Maneuver ship as required
20 - Check for other threats
21 - Respond to further threats
22 - Confirm enemy target destroyed
23 - Assess implications of damage to own ship from missile (etc.) hit
24 - Regain own global awareness
25 - Re-focus OR team. Re establish command presence
26 –Stand down own weapons
27 - Stand down ship
28 - Report to/from TG

Table 2.2 - CTA Goals (Matthews et al., 1999; Matthews & Webb, 2000).

2.3.2 Mental representations

A major finding of the CTA was OROs' widespread use of various forms of mental representations. Such internal representations occurred for all ORO goals and tasks, not just those related to threat assessment. OROs described their mental representations during the CTA in many different ways. In some cases, OROs described a mental image that comprised a number of mental pictures with *iconic*-like properties arranged and organized according to a simple conceptual structure. In other cases, the model appeared to be more complex and took the form of a structural representation of knowledge, processes, or plans.

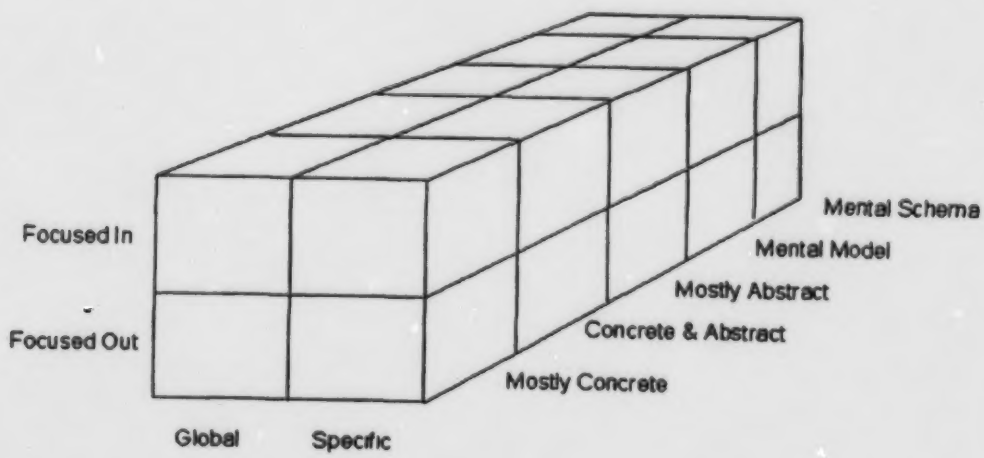

Figure 2.1 - Structure of Mental Representations Based on Three Dimensions (Focus, Domain, Abstraction)

Although the OROs interviewed in the CTA never expressed with absolute clarity the nature of their mental representations, certain consistent themes emerged to suggest that there are multiple forms of representation. Matthews et al. (1999) developed a categorization scheme based on three dimensions, which may vary in their permutations or combinations for any particular representation. These dimensions are level of abstraction, level of focus, and domain of interest, which are illustrated in Figure 2.1. Any specific mental representation can be categorized in terms of the three dimensions.

2.3.2.1 *Level of abstraction*

This aspect of the mental representation concerns the relationship between the representation and the data on which it is based and is reflected along a concrete-abstract dimension. Working distinctions have been made in the literature between a *mental picture*, a *mental model*, and a *schema*, which differ among themselves in terms of their level of abstraction/generality and level of "conceptualness" vs. "perceptualness."

A '*mental picture*' is the least conceptual and most specific. It is exactly what the name implies, a graphic visualization of some aspect of the existing operational environment, or projection of a future state, or recall of an earlier state. The mental picture contains primarily perceptual information and conceptual information to a much lesser extent. The picture may be simple, directly reflecting the data on which it is built (e.g., an image of the raw radar return), or complex, integrating and interpreting data (e.g., visualizing the data return of a contact as a particular vessel at some distance and bearing from the ship). Given the flexibility of mental imagery, Matthews et al. (1999) distinguished three levels of abstractness corresponding to mental pictures.

- *Category 1 – Most concrete*: At one end of the concrete-abstract dimension OROs describe a mental picture that accurately images or reflects the data on which it is based. Such a representation could be an image of the plot, a situation display, or a state-board. The important element of this type of representation is that the ORO can internally "read-off" the data from the picture some time after turning attention away from the original source.
- *Category 2 – Concrete and abstract*: At the next level, a mental picture possesses image-like qualities but also represents some degree of abstraction from, or integration of, the data on which it is based. An example of this might be a general picture of the task group as a single entity, its relationship to a distant surface contact that has launched a missile that is closing and the appearance of an unidentified air radar track. Such forms of mental picture might typically combine specific aspects of information across the maritime and air domains.
- *Category 3 – Mostly abstract*: At a higher level of abstraction, the mental picture represents situations described by OROs in which they envisage aspects of the task environment in which conceptual or meaningful elements are more important than spatially veridical relationships (e.g. distance, exact location, bearing). Examples might include: visualizing damage or potential damage to various areas of the ship, or task group, and projecting the consequences, memorizing the status of equipment, or equipment characteristics such as radio frequencies.

Beyond image-like representations, it is possible to create highly conceptual representations. A '*mental model*' has been defined as an internal representation that has a similar relationship-structure to that of the processes it imitates (e.g., Glenberg, Meyer, & Lindem, 1987; Johnson-Laird, 1983). Such models are thought to underlie many aspects of human reasoning and are seen as paralleling the working of the processes they represent. A mental model is a conceptual representation of a specific system or situation; it contains information about the elements (objects, people) that are actually in the system, it represents relationships that really exist between the elements. The general purpose of the model is to represent the physical nature of the system (things, actions, etc) and the conceptual structure (how are things related to one another). Like a physical model, the mental model does not imply any specific view or interpretation of the system; rather it can be potentially viewed from any perspective. Thus, mental models comprise a fourth level of abstraction:

- *Category 4 – Mental model*: These forms of representation are used by OROs to support a range of functions that involve planning or anticipating future actions or processes, and where the structural aspects of the model and conceptual understanding tend to be more important than the associated data. These models may support overall mission-related issues such as mission intent and planning, reasoning about Rules of Engagement

(ROE), and understanding the enemy, own force resources, and surrounding civil activity. Some of these mental models are quite stable over time and circumstances, such as the pre-plans for the ship and the TG and the situations in which these plans would apply.

At the highest level of abstraction is the '*mental schema,*' which can be thought of as a mental representation of a general type of system or situation and contains very conceptual information about the kinds of objects, people, etc. involved and the relationships between elements. Thus, the ORO's schema might apply to the generic capability of the ORO and refer to the kinds of things typically found in an OR, the types of actions and processes, and the relationships between things that go on in an OR. The schema would not refer to any particular OR in the context of a particular process, and no real OR would have all the elements of the schema.

- *Category 5 - Mental Schema*: An ORO's mental schemata are likely based on extensive training and operational experience, which provide domain knowledge. Schemata are organized by key functional areas, which make them readily accessible during problem solving and decision making (** REFS **). A mental schema can serve as a template for creating a specific mental model to represent the situation at hand. It can also serve as a knowledge base for making assumptions, extrapolations, and hypotheses.

2.3.2.2 Level of Focus

Level of focus is the second dimension of the mental representation that emerged from the CTA. The most typical example encountered was a distinction OROs frequently made along dimensions of scale, range, or time. For example, *"ranged in"* represents a close range view within the maritime or air domain. This is usually associated with a "zoomed-in" display and is used for a variety of purposes where the time frame is short or distances relatively small. The representation is frequently an internal, picture-like image that preserves essential object information and spatial relationships. The information may be a direct representation of the way data are presented on a single display, or may combine some selected elements from different sources. Examples where such an image would be created, and referred to, might include local navigation with respect to other ships in task group, other close surface vessels or navigational hazards and shoreline. In an air context it might be related to positioning the ship to minimize its radar profile and tactical manoeuvring for a missile threat.

In contrast, *"ranged out"* might also be called "wide range" view within maritime or air domains. This form of representation has all of the characteristics of the local view except that the scale (time or distance) is greater. It may be associated with a zoomed out display and is used for a variety of purposes, such as when the ORO is trying to build a picture of the relationship of new contacts to the ship, to task group and other selected environmental features.

2.3.2.3 Domain of Interest

The third dimension along which mental representations differ concerns the warfare domain of interest. We mean by this whether the ORO's attention is directed to primarily air, surface, sub-surface or to some combination of these. At any one time an ORO may be trying to maintain a mental picture for each separate warfare area, within a model that provides an overall purposeful plan of action. Depending on the contextual circumstances, this picture may also vary along the degree of abstraction and also the level of detail. This within-warfare domain mental picture can be

contrasted with what OROs frequently called the "***global picture***" or the "*big picture*". At one level it is an *integrated* mental picture composed of a number of pieces of information selected from different displays or other data sources and integrated across surface, sub-surface or air warfare areas. Hence, it is relied upon extensively in multi-threat contexts as well as in situations where the overall mission intent and strategic picture may be the areas of focus. In addition to such a threat-oriented global picture, OROs also described higher level global pictures. These tend to incorporate dimensions that are mission and resource related, take a task group rather than a ship perspective, and involve some appreciation of relative priorities and the overall global threat situation.

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3 TADMUS Decision Support System

The TADMUS project was undertaken after two tragedies struck the US Navy. The USS *Stark* was severely damaged by an attack and 27 US naval personnel lost their lives when the commander decided not to engage an inbound aircraft that was judged not to be a threat (Hutchins, Morrison, & Kelly, 1996). In contrast, the commander of the USS *Vincennes* made the decision to engage an inbound aircraft that was judged to be a threat, an aircraft that turned out to be a commercial airliner, resulting in the deaths of all personnel aboard the aircraft (Hutchins et al., 1996). The purpose of the TADMUS project was to conduct research in the areas of human factors and decision making to find applications that can help avoid these types of events in the future (Morrison, Kelly, Moore, & Hutchins, 1998).

As part of this project, researchers developed a concept for a Decision Support System (DSS) to be used in exploring tactical decision making. The TADMUS DSS was designed to support the decision making of command-level (CO and TAO) decision makers aboard the AEGIS class cruiser (Hutchins, 1996). The overall goal of the TADMUS DSS is to improve SA and decision making by helping personnel identify critical contacts earlier and more accurately and to determine and initiate appropriate responses at the right time (Morrison et al., 1998).

The TADMUS DSS was developed with the specific objectives of (Morrison, Marshall, Kelly, & Moore, 1997):

- Minimizing the mismatches between cognitive processes and the information available in the Combat Information Center (CIC) to facilitate decision making.
- Mitigating the shortcomings of current CIC displays in imposing high information processing demands and exceeding the limitations of human memory.
- Transferring the data in the current CIC from numeric to graphical representations wherever appropriate to facilitate the interpretation of spatial data.

The TADMUS DSS is based on the principle that modern warfare places a premium on rapid identification of contacts and selection of Courses of Action (COAs) (Hutchins, 1996). Kaempf et al. (1996), for example, found that in an anti-air mission simulation, 103 of 183 decisions involved situation assessment. Thus, a primary function of the DSS is to help the operator focus on relevant data. It also reduces the operator's mental workload by performing some information and data processing. The processed data allows the operator to see important variables and relationships rather than search for or infer them from tabular or text data (e.g., Hutchins, 1997).

The general design principles of the TADMUS DSS are to (Hutchins, 1996):

- Help the user anticipate future events by portraying contact history.
- Help the user identify stored patterns of events.
- Display planned responses for anticipated events to facilitate COA selection.

In other words, the DSS was designed to provide indicators of relations between data features, structural similarity between sequences of features, and evidence of relationships.

The designers of the TADMUS DSS applied two intuitive models of decision making, namely feature matching and story generation (Hutchins, 1996; Hutchins, Morrison & Kelly, 1996). According to these models (and similar ones, see Klein, 1997), decision makers first appraise the situation in order to classify it as familiar or not, based on experience. The assessment of familiarity can be made in several ways, including:

- Recognition by matching features of the situation to prior events.
- Recognition of a whole pattern of features that fits a familiar story or scenario.
- Explicit recall of an analogy from another related domain.

Thus, decision makers may rely on sets of features or dimensions that can be used to distinguish distinct classes of events. These features can be extracted on their own or identified in stories or schematic situations that have been developed through experience.

The TADMUS DSS is designed to help operators categorize incoming data by processing data and presenting it in a form that highlights important features and relations. The operator can use the categorized data to match the current situation to a mental template based on experience. The DSS also provides tools to help operators organize their COAs in response to threats. Thus, the focus of the DSS is on situation assessment and response but that also relies to a great extent on operator knowledge.

The DSS is organized into six modules that carry out these functions (see Hutchins, 1996; Rummel, 1995). These modules are described below.

Geo Plot. This window presents a map of the area around the ship. Surface, subsurface, and air contacts are overlaid on the map.

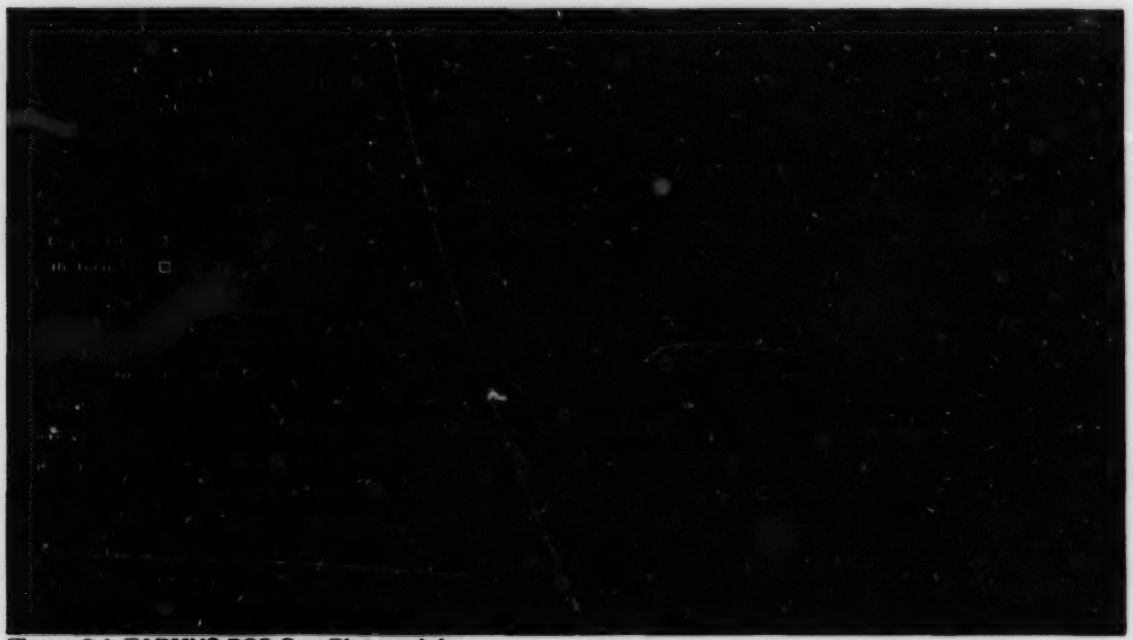

Figure 3.1. TADMUS DSS Geo Plot module.

The Geo Plot offers options to display information about the environment, including the coastline and land topology (based on charts contained in the DSS database). When selected, this information is placed in the background of the display. In addition, the Geo Plot offers options to display various contact data, including track numbers, course leaders, track histories, and weapons ranges (for hooked contact and own ship only).

Track Summary. This window presents detailed contact parameter information pertaining to the selected or "hooked" contact.

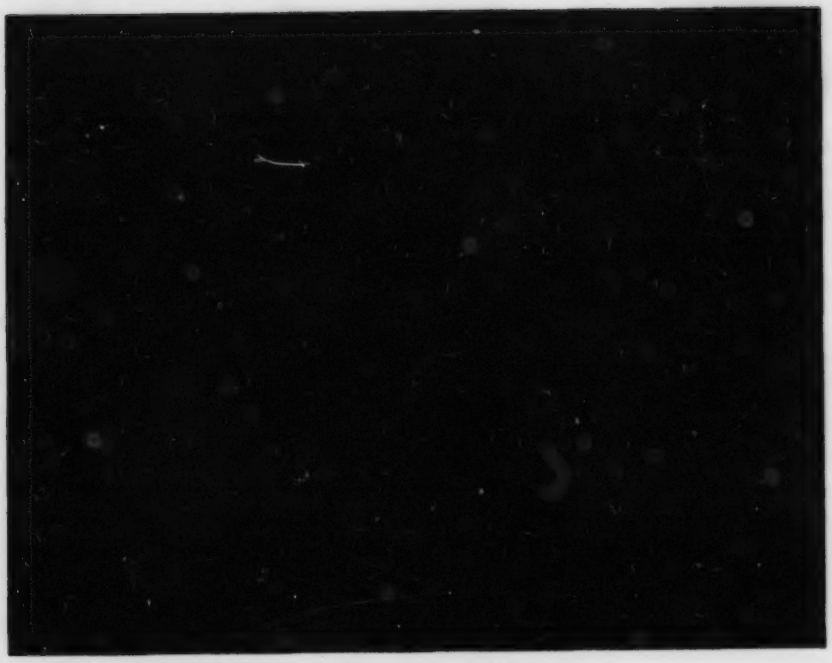

Figure 3.2. TADMUS DSS Track Summary module.

Track Profile plus Aspect Window. This window depicts the speed, altitude, course, and range of a single contact on a two-dimensional (2D) display with contact and own ship weapon ranges indicated. The histories of the parameters are plotted against time so that changes in any of the parameters becomes apparent immediately. This facilitates use of a recognition strategy because the operator does not have to remember previous values to compare past states to the current state.

Figure 3.3. TADMUS DSS Track Profile plus Aspect Window module.

Response Manager. This window assists the operator in using preplanned responses against the selected or "hooked" contact by graphically depicting preplanned responses that need to be taken given the current data. In particular, it indicates the earliest and latest points at which specific actions (e.g., deploy chaff, fire missile) can be taken.

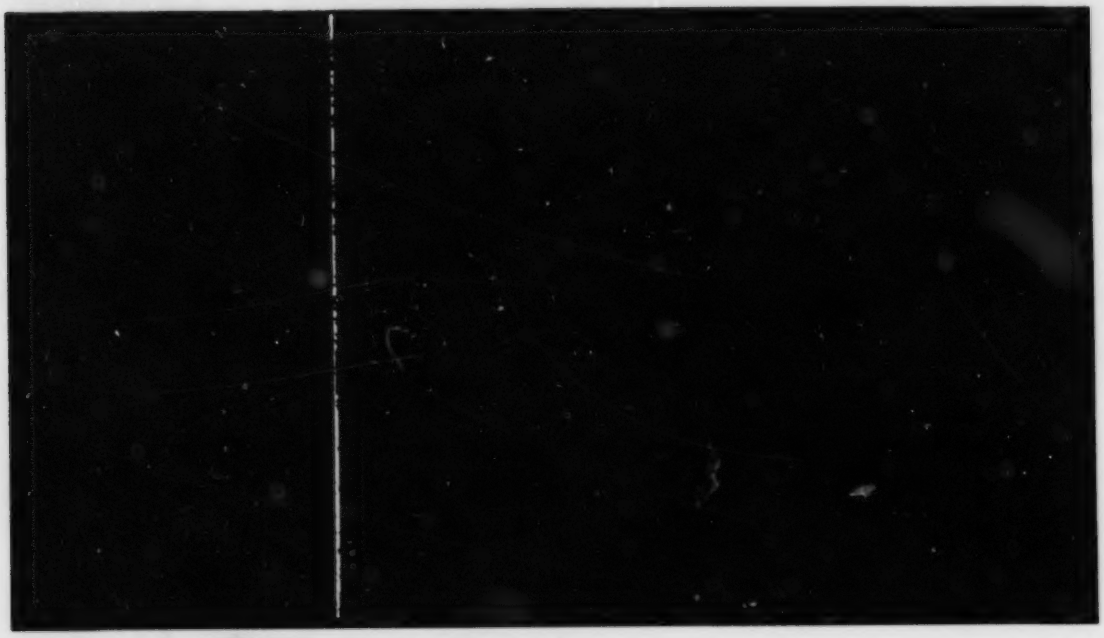

Figure 3.4. TADMUS DSS Response Manager module.

Basis for Assessment. This module is an expert system that uses explanation-based reasoning to generate possible accounts for the current data. The goal is to generate explanations for sensor tracks that best account for the available data. It provides multiple explanations to the user to help him or her evaluate possible identifications of tracks. Explanations take the form of simple causal models that indicate what outcome is expected given the data available. This module also incorporates a *critic* function (Hair & Pickslay, 1993). This provides the user with criticism of his or her on-going decision process to improve the quality of the solution that is adopted. The critic focuses the user's attention on salient pieces of data (as judged by the database) to ensure that the user does not overlook data due to cognitive biases.

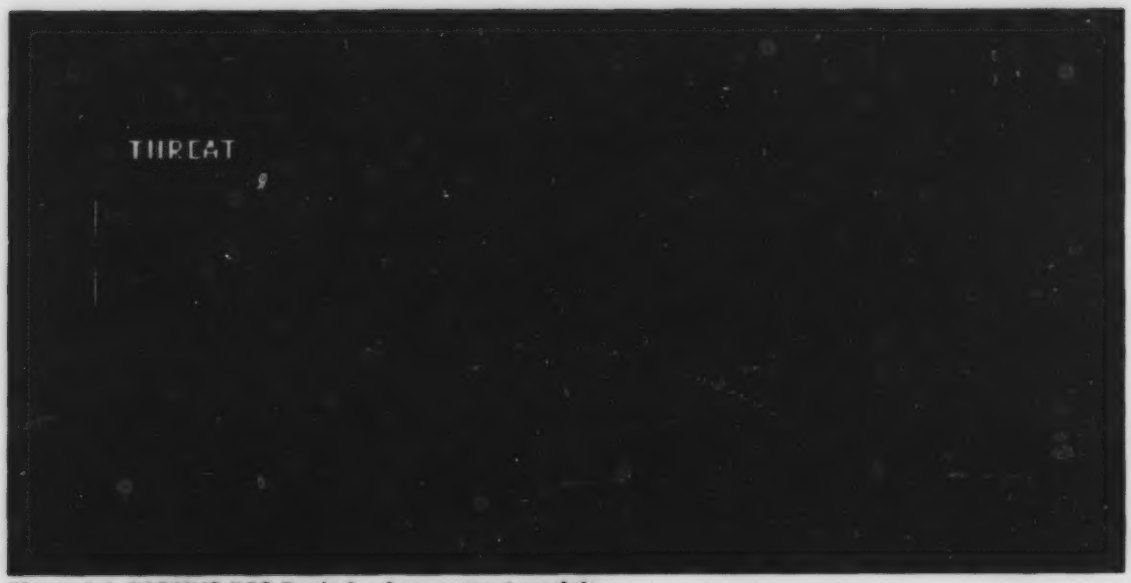

Figure 3.5. TADMUS DSS Basis for Assessment module.

Mini Character Read-Outs (CROs). This window focuses on several contacts at once and helps the operator monitor multiple contacts. It prioritizes contacts to indicate the most important to monitor and act upon. It also indicates the identification and relevant summary data concerning contacts. Alerts (text messages) can be accessed through the CROs by pressing the "alerts" button for a track. Pressing this button brings up a display containing recent alerts pertaining to that contact.

Figure 3.6. TADMUS DSS CRO module (only 4 of 16 CROs shown).

The modules are arranged in order of information complexity (or data richness) from the top of the display to the bottom. At the top are the track summary, track profile, and geo plot, which all deal with analyzing and identifying a single contact. The basis for assessment and response manager provide more detailed analysis of a particular contact and actions with which to deal with it and are located in the middle of the display. The CROs present information on all contacts requiring attention or action and are located at the bottom of the display.

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4 Work Domain Model

The main focus of this project was to review the TADMUS DSS with respect to the CTA goal and mental representation frameworks. Burns and Bryant (2000), however, have previously conducted a review of the TADMUS DSS with respect to a work domain model for the HALIFAX class frigate The goal of their review was to determine the extent to which the TADMUS DSS supported control activities in the HALIFAX class work domain.

4.1 Work Domain Analysis

Work Domain Analysis (WDA) is a technique for creating a model of the *environment* in which human operators solve problems and the affordances and constraints in that environment that shape cognitive work (Vicente, 1999). The goal of WDA is to study the nature of the environment, from its purpose to its physical components.

A WDA is completed by defining system boundaries and developing and abstraction hierarchy. The system boundary defines the system to be analysed whereas the abstraction hierarchy is a means-end model of that system. The work domain is assumed to exist to achieve a purpose so that the means-end hierarchy defines how that purpose can be realized. There are five levels to the abstraction hierarchy:

1. Functional Purpose (overall purpose);
2. Abstract Function (first principles);
3. Generalised Function (processes);
4. Physical Function (equipment and system capabilities); and
5. Physical Form (location, condition, appearance of systems).

4.2 Work Domain Model for the Canadian Patrol Frigate

Burns and Bryant (2000b) developed a work domain model for the HALIFAX class based on design and procedural documents and Subject Matter Expert (SME) input.

4.2.1 System Boundaries

Establishing the system boundaries of the HALIFAX class frigate was challenging because the frigate is not a closed system. The frigate acts within a larger military system (Navy, DND) but has its own mission or intent to accomplish. In most cases, this intent involves interacting with other parties with different intents. For this analysis we will refer to other entities as "the contact" to avoid assigning a positive or negative intention to the entity and, as well, to indicate that this entity may very well be unknown or poorly understood.[1] By contact we are referring to another intentional entity, be it friend, hostile, air, surface, or subsurface. The domain of this party, while primarily under its own control, is still part of the domain of the frigate because the frigate can apply its resources to change the other contact's resources and similarly, the contact can alter the

[1] The single contact presented in the work domain model is merely a placeholder all possible contacts; there will always be many contacts in the environment, each with its own intent.

resources of the frigate. For these reasons, both the frigate and a contact need to be included in the work domain.

The two domains have been shown in Table 4.1. To indicate the interaction between them, a dashed line has been used to separate them. Both domains interact with the physical environment that has been modeled in the middle column. Although the environment affects the capabilities of both parties, it is not a domain in the same sense since it is not purposeful.

	Domain of Own Resources	Domain of the Environment	Domain of Contact Resources
Functional Purpose	accomplish frigate mission		accomplish contact intent
Abstract Function	own priority functions, balances and conservation laws	conservation laws	contact priority functions, balances and conservation laws
Generalised Function	locomotion processes of response	environmental processes	locomotion processes of response
Physical Function	physical capability of own resources	physical capability of weather and environment	physical capability of contact resources
Physical Form	condition, location, appearance of own resources	condition, location, appearance of weather and environment	condition, location and appearance of contact resources

Table 4.1 - Two domains interacting through a shared environment.

4.2.2 Abstraction Hierarchy

Functional Purpose level. Functional purpose is a description of designed for purposes. In the most generic sense, the frigate exists to accomplish its mission. Practically, since the frigate is not an entity in isolation, this mission propagates down from the higher level groupings represented in Table 2.1, from the task group, and navy interests, etc. Accomplishing its mission is a generic placeholder for all the different missions that could be assigned to the frigate. In the same way, the contact party has some intention that it is attempting to accomplish. For now, the environment is not modeled as having an intent and can be considered unintentional.

Abstract Function level. The abstract function level describes physical laws, conservation laws, and in social systems, the social priority functions which determine how decisions will be made. A frigate must work within physical constraints of mass and energy conservation and must work within the constraints of buoyancy so as not to sink. The frigate must also manage resource balances such as fuel and supplies. To a lesser extent, the frigate operates within a social environment that may impact its decision making. For the environment, the abstract function level is a description of physical laws of the environment. The contact abstract function level is similar to the frigate. The contact will operate within the constraints of its own priority functions that may be quite different from those of Canadian frigate.

Generalised Function level. The generalised function level describes the processes by which the priorities are met, using the functional capabilities of the work domain described in the Physical Function level. For the generic description of the frigate we have used the processes of locomotion, and the processes of response. Simply put, the frigate must go *somewhere*, and then do *something*. This generic description is also used for the contact as it is assumed that it must also go somewhere and do something. For the environment, major environmental processes are described.

Physical Function level. This level describes the physical capability of the frigate and its equipment. Simply, what can it do and how well can it do it. The physical capabilities of the contact are also modeled. For the environment, its capability to aid or to impede the capabilities of the frigate or the contact are described.

Physical Form level. This level describes the condition, location, and appearance of the frigate, its resources, the environment, the contact and its resources.

4.3 Analysis of the TADMUS DSS

As part of a project examining the feasibility of performing a WDA for the HALIFAX class frigate, Bryant and Burns (2000) reviewed the TADMUS DSS. The goal of that review was to make a first identification of elements in the TADMUS DSS that might be reusable in the HALIFAX context based on the results of the work domain model (Burns & Bryant, 2000b). Bryant and Burns (2000) identified links between DSS elements to compare the organization of the DSS to that of the CWA model. This effort was facilitated by performing a series of task simulations by working through a representative set of ORO tasks (primarily air and surface threat detection and response).

To illustrate the content overlap of the TADMUS DSS to the HALIFAX class work domain, Bryant and Burns (2000) created a set Functional Information Profiles (FIP) (see Burns & Vicente, 1996). The abstraction-aggregation space embodied in the work domain model defines the information needs in problem solving in the domain. A FIP indicates which areas of information needs are addressed by the system. In other words, the FIP serves as a map of the information displayed by the system compared to the work domain space.

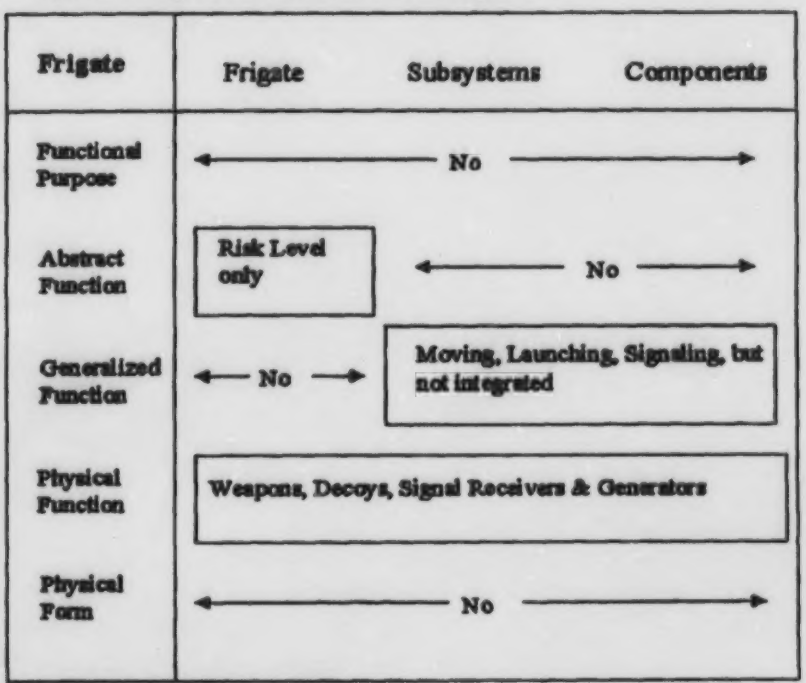

Figure 4.1. FIP for the Frigate Domain

The FIP for the own ship domain is presented above (Figure 4.1). The vertical axis indicates the abstraction hierarchy and the horizontal axis the decomposition from overall system (own ship plus environment plus contact) to subsystem (the major parts of the system such as navigation subsystem) to components. The boxes indicate the areas of the work domain for which the TADMUS DSS provides relevant data or information. It is important to note that the FIP does not indicate the quantity or quality of information provided by the TADMUS DSS. In general, the TADMUS DSS provided only limited information pertaining to any given level of the abstraction hierarchy.

As can be seen in the figure, the TADMUS DSS presents no information about functional purposes. It does present assessments of contacts as threats, unknowns, or friends, which provides some indication of the risk level for the frigate associated with each contact. The DSS presents considerably more information pertaining to generalized functions, including movement, launch of resources, and emitting and receiving signals. Information about these processes, however, are not always integrated. The DSS also presents a great deal of information at the physical function level. This is also incomplete as it covers weapons, decoys, and signals but no aspects pertaining to movement or other physical processes of the own ship. The DSS presents no information about the physical form of the system or subsystems.

The FIP for the contact domain is shown in Figure 4.2. The TADMUS DSS presents more information about the contact than the own ship, although generally at the same levels of abstraction. The DSS presents limited information that the abstract function level in terms of threat status but more extensive information at the generalized function and physical function levels in terms of movement, weapons, and sensor processes. This information tends to be more integrated than the information presented about the own ship. That is, the Track Summary and CRO modules present movement, weapon, and sensor information together. This creates an indication of risk, although the operator must combine these data to make a risk judgment.

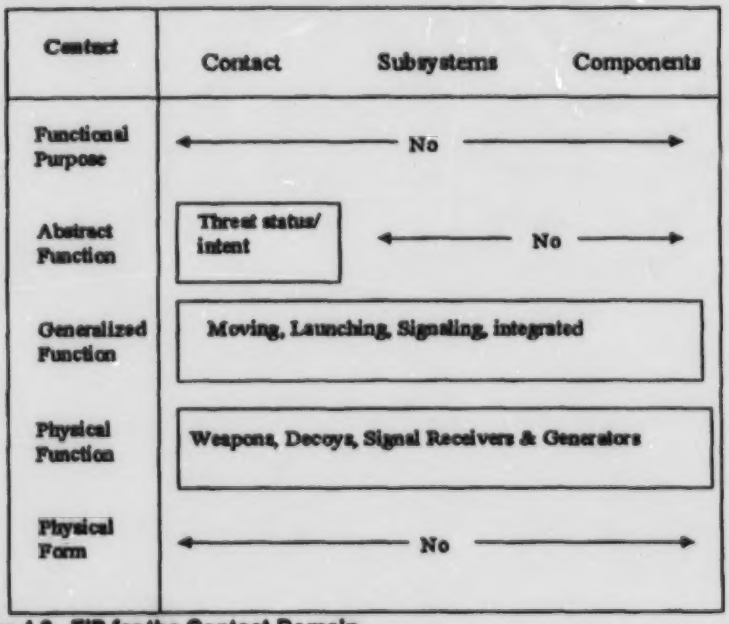

Figure 4.2. FIP for the Contact Domain

The FIP for the environment domain is shown in Figure 4.3. Unlike the own ship and contact domains, the distinction between system, subsystem, and components is not relevant and Figure 5.3 shows the representation of the domain for the whole environment. As can be seen, the environment is represented only at two levels of abstraction. At the generalised function level, the DSS provides some information useful for judging the effects of landforms on movement and sensors. This comes in the form of the map display and the optional contour display that indicates elevation of landforms. At the physical function level, the DSS indicates the locations and shapes of landforms and water space. The environment is the least represented aspect of the work domain in the TADMUS DSS. In fact, this information is contained in only one module, the Geo Plot. The most significant feature of this display is that it provides no information concerning environmental factors that could affect movement, weapons, or sensors.

Environment	Environment
Functional Purpose	← No →
Abstract Function	← No →
Generalized Function	Limited info for judging land effects
Physical Function	Location of land & water
Physical Form	← No →

Figure 4.3. FIP for the Environment Domain

4.4 Other Frameworks

The work domain model developed by Burns and Bryant (2000b) reflects one conceptualization of the work domain of the HALIFAX class frigate. Chalmers, Easter, and Potter (2000) also performed a work domain analysis of that domain, as well as a decision analysis for the ORO position. Based on their analysis, they developed a different abstraction hierarchy than Burns and Bryant (2000b). Chalmers et al.'s (2000) abstraction hierarchy focused on the functions and tasks performed by the ORO as a means to identify the cognitive demands placed on the ORO. The cognitive demands served as a basis for developing visualization concepts to support the ORO's work. Thus, the WDA framework discussed in this report is only one possible version.

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5 Method

5.1 Procedure

The TADMUS Decision Support System (DSS) was reviewed by comparing the information content of the TADMUS DSS to that of the Operations Room Officer (ORO) mental representation dimensions identified in a CTA by Matthews et al. (1999). The goal of the review was to determine what ORO mental representation dimensions are supported by the TADMUS DSS.

The review was completed by the following steps:

Prior to the review, the author:

- Mapped ORO goals onto ORO mental representation dimensions to create a framework for describing ORO information needs.
- Created a list of ORO mental representation dimensions associated with ORO goals. In addition, this framework was mapped onto the abstraction hierarchy of the work domain model developed by Burns and Bryant (2000b).
- Created a datasheet to record, for each ORO mental representation dimension and CTA goal, whether there is an element in the TADMUS DSS that corresponds to that dimension or goal, how the TADMUSS DSS element was linked to other elements, and comments pertaining to the degree to which the TADMUS DSS element corresponds to the ORO mental representation dimensions and CTA goals.

During the review, the author:

- Inspected each module of the TADMUS DSS, reviewing all screens and components. Using the datasheet, the author recorded all elements of the TADMUS DSS in relation to the ORO mental representation dimensions and goals.
- Created a list of TADMUS DSS elements, categorized by module, and indicated which elements do not have a corresponding element in ORO mental representation dimensions and goals.
- Performed a series of task simulations by working through a representative set of ORO tasks (based on scenarios contained in the TADMUS DSS simulation software). The author assessed for each task simulation the functional value of TADMUS DSS elements for each module of the DSS. Note, this step was not intended to provide a comprehensive evaluation of the DSS but to provide information pertaining to how DSS elements are used in relation to the structure and purpose of ORO mental representations and goals.

The review was conducted in a one-day session on February 12, 2001, using TADMUS DSS simulation software provided by DCIEM.

5.2 TADMUS Simulation

The TADMUS Project Decision Support System (DSS-II) Version 4.6 was reviewed in this study. This software was developed in 1999 as part of the U.S. Navy's TADMUS program by Space and Naval Warfare Systems Center, San Diego (SSC SD) and Pacific Science and Engineering Group Inc.

The software is a computer-based experimental tool rather than a functional DSS. The software provides an easily configurable tactical information interface that can be used to study:

- Tactical decision making processes in realistic operational environments;
- Aids to decision making; and
- Advanced HCI concepts and designs.

The software was not intended to be a finished product for fleet use nor a prototype product, engineering development model, or production aid.

5.3 Potential Limitations

Although this procedure allowed a review of the TADMUS DSS, the following issues must be considered before interpreting the results of the review.

- Evaluation of the DSS in terms of how well it corresponds to the analysis of ORO mental representations and goals is not sufficient to provide an evaluation of the usefulness and usability of the DSS. Absence of ORO mental representation elements or goals in the DSS suggests limits on the usefulness of the DSS, at least in terms of information provided to the operator. However, the converse, the presence of those elements in the DSS, does not necessarily indicate a positive degree of usefulness or usability. Just because ORO mental representation elements are represented in the DSS does not mean that the elements are processed or displayed in a usable way. Any evaluation of the TADMUS DSS in the context of ORO mental representations should be coupled with a usability evaluation.
- We will perform only a one-day review by the author, which limits the depth and generalizability of the review. SMEs with experience in naval operations (i.e., active or former OROs) could undoubtedly provide greater insight into the relation of the TADMUS DSS to ORO goals and mental representations.
- The TADMUS DSS was developed by and for the United States Navy, which has different strategic, tactical, and operational priorities than the Canadian Navy. This limitation must be dealt with by identifying key departures of Canadian concerns from those of the United States and incorporating these in any future review of TADMUS systems.
- The TADMUS DSS simulation software used in the review contained no scenarios dealing with subsurface threats, limiting the opportunity to explore all aspects of the ORO role. It is unclear what, if any, responsibilities the TAO has for subsurface warfare. It is likely that the TADMUS DSS was not designed with that warfare area in mind.

6 Results and Discussion

6.1 The TADMUS DSS Modules

We will begin discussion of the results of the review by summarizing the information content of each TADMUS DSS module. This discussion largely follows the analysis of Bryant and Burns (2000) but reflects several minor differences between the version of the TADMUS simulation software reviewed here and the version reviewed by Bryant and Burns (2000). This part of the review is shown in tabular form in Annex A.

6.1.1 Geo Plot

The Geo Plot is a map display that shows the physical environment of land and sea areas. A navigation chart and topographic map for land areas can be displayed in the background. Even when the navigation chart is not displayed, coastline and shallow water areas can be displayed. Overlaying the map, the module presents the locations of the own ship and all contacts (friend, unknown, and hostile) plus velocity leaders to indicate course and speed. Relative speeds of tracks are indicated by velocity leaders. Own movement must be inferred by changes in the positions of land forms relative to own ship (i.e., the display is a ship-centered map). The Geo Plot also gives the operator the option of viewing air lanes, weapon ranges (self and contact), and land form contours.

6.1.2 Mini-Character Read Outs (CROs)

The CROs summarize the 16 highest priority tracks (priority is based on output of the Basis for Assessment module). Each readout indicates the contact's:

- Classification (threat, unknown, friendly) or specific identification if possible (e.g., ship name, type of aircraft, etc.).
- Range and bearing from own ship.
- Altitude.
- Sensor type being emitted.
- IFF status (on or off).
- Most recent alerts (in a pop-up box).

6.1.3 Track Summary

The Track Summary provides a summary of data pertaining to the selected contact. It shows the track ID, bearing, course, range, speed, and altitude. This module also presents historical data for these last five parameters (e.g., "bearing constant," "altitude increasing," etc.). The Track Summary indicates the contact's EW status (emitter type if any detected), the type of platform(s) with which the emitter is consistent, and IFF status (on or off). The age of the contact is presented to indicate how long it has been recorded by the system. Finally, this module presents the assessment of the contact made by the Basis for Assessment module, which indicates whether the contact is judged to be a threat, unknown, or friend. A related field indicates the status of the contact (e.g., "immediate" threat, etc.). The last alert pertaining to the contact is also shown.

6.1.4 Track Profile with Aspect Inset

The Track Profile shows a plot indicating the maximum ranges of the contact's presumed weapon and the own ship's selected weapon. In the case of air contacts, the plot displays altitude versus range, whereas for surface contacts the plot displays range only. The selected contact is plotted by its range from the own ship (and altitude for air contacts) to indicate whether the contact can engage the own ship and whether it can be engaged by the own ship. Thus, the Track Profile creates:

- A contact weapon envelope – a plot of ranges and altitudes at which the contact's presumed weapon can be fired at own ship.
- An own ship weapon envelope – a plot of ranges and altitudes at which the selected weapon can be fired at the contact (changing perspective allows a plot of another friendly unit's weapon envelope).

The display shows the track history, which is a record of altitude by range position of the selected contact over time. This information can be used to determine whether the contact is moving in a way to suggest it will launch weapons.

The Aspect Inset shows possibilities for ship positioning to deal with the selected contact.

6.1.5 Response Manager

The Response Manager shows the ordered list of actions that can be taken, plotted against the range of the selected contact from the own ship. Actions are arranged in the list by their degree of escalation so that the topmost actions entail low levels of conflict and the actions become increasingly hostile descending the list. Actions that have already been taken are grayed-out to highlight them. To further aid the operator, this module indicates whether the contact is closing or opening, which may suggest its intent.

6.1.6 Basis for Assessment

The Basis for Assessment module presents the output of the DSS's expert system. This module shows the DSS's interpretation of available sensor data and its classification of the selected contact. Evidence for and against each possible classification (i.e., what sensor data and inferences about contact behavior, identity, and capabilities are consistent with the classification) is available. The operator selects a given classification (threat, unknown, friendly) and the module displays the appropriate evidence. The module automatically presents the evidence pertaining to its classification judgment. In addition to the evidence, the Basis for Assessment presents the list of necessary assumptions for a classification to be true (i.e., aspects of the contact's physical state, course, radar on/off, etc., and its intent).

6.2 Review Data

To organize observations, a datasheet was created prior to the review. A sample of the datasheet is shown in Figure 6.1, reduced in size to fit this page. The datasheet listed the ORO goals identified in the CTA (Matthews et al., 1999; Matthews & Webb, 2000) with a column ("Present?") to indicate whether the TADMUS DSS presented sufficient information to support each goal. This was done by a subjective assessment on the part of the author as to the extent to which the TADMUS DSS could be used to perform tasks that achieved or partially achieved each goal.

Annex A provides the datasheets containing the observations of the TADMUS DSS made February 12, 2001. The presence of TADMUS support for a goal was rated as either present ("Yes" in the datasheet), "partial," or not present ("No"). A column provided space for comments on the nature of support for ORO goals.

For each ORO goal there was also a set of boxes under the "Mental Representation" column, which were used to rate the kind of mental representation best supported by the TADMUS DSS along the three dimensions identified in the CTA report (Matthews et al., 1999). This rating was based on the author's subjective judgment of the nature of the mental representation an operator would likely create given the data and information available from the TADMUS DSS. Care was taken to base the ratings only on the content of the DSS itself as distinguished from other potential sources of support, such as other displays, manuals and notes, or the operator's domain knowledge. A column provided space for comments on the nature of support for ORO mental representations.

CTA Goal	(Present?	Comments (Yes)	Mental Representation		Comments
1 - Visualize external environment			Abstractness	Level of Focus	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	
2 - Update own knowledge for coming watch from text msg information.			Abstractness	Level of Focus	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	
3 - Establish schedule of anticipated events for watch.			Abstractness	Level of Focus	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	

Figure 6.1 - Section of the datasheet used to record observations of the TADMUS DSS

6.3 Goal Analysis

To better appreciate the ways in which the TADMUS DSS supports operator performance and to relate that support specifically to the ORO position, it was necessary to categorize goals in a different fashion than Matthews et al.'s (1999) original division into coming on watch, background, and threat-related goals. The ORO goals generally fell into a few well-defined categories. These categories reflect broad aspects of the ORO's job rather than specific tasks. The ORO goals were divided into the following categories:

- Goals associated with team management;
- Goals associated with system and sensor management;
- Goals associated with management of ROE, orders, and legal limits;

- Goals associated with communication (internal and external);
- Goals associated with building the tactical picture; and
- Goals associated with managing the response to a contact.

Table 4.1 lists the ORO goals divided into these categories. The largest categories are team management, picture building, and managing the response to a contact, suggesting that OROs devote a great deal of attention to these areas. In contrast, system/sensor management, management of ROE/legal limits, and communication may consume less attention. The column in Table 4.1 marked "TADMUS?" indicates the level of support for ORO goals provided by the TADMUS DSS. Entries in this column are taken from the datasheet in Annex B.

Goal Category	TADMUS?	Goals
Team Management		*Coming on Watch Goals*
	Partial	3 - Establish schedule of anticipated events for watch.
	Partial	5 - Establish current activity and work focus among OR teams
		6 - Establish required action items during watch
		11 - Focus OR team on issues for coming watch
		12 - Establish command presence
		Background Goals
		1 - Monitor and manage the OR team
		Threat Response Goals
	Partial	2- Ensure OR prepares quick first response, broad plan for worst case
		3- Optimize work among OR team(s)
	Partial	10 - Ensure OR detects missile firing and establish firm radar track
		13 - Make CO aware of all relevant components of the plan Get feedback from CO
		14 - Ensure all OR team aware of plan. Emphasize key points
		16 –Ensure standard procedures completed correctly (ZIPPO, etc)
		18 - Back up Warfare Director (WD) as required
		25- Re-focus OR team Re establish command presence
System & Sensor Management		*Coming on Watch Goals*
	Partial	7 - Review OR system performance (sensors, etc) and rectify/ work around
		10 - Optimize own CCS
		Background Goals
		3 - Monitor and manage OR equipment capability
		Threat Response Goals
		23- Assess implications of damage to own ship from missile (etc) hit
		26 –Stand down weapons
		27 - Stand down ship
Management of Authority (ROE, orders, etc.)		*Coming on Watch Goals*
	Partial	8 - Comprehend items in CO's order book
		13 - Review pertinent pre-plans, procedures, and ROE for coming watch
		Background Goals
		9 - Maintain awareness of ORO's authority to act
Communication		*Coming on Watch Goals*
		10 - Check outgoing message traffic (text, voice)
		Background Goals
		4–Optimize information flow within and outside OR
		Threat Response Goals
		7 - Establish communication with contact to resolve identity and intentions
	✓	8 - Conduct warnings in accordance with TG tasking
		28 - Complete and send reports

Table 6.1 - Categorization of ORO Goals (✓ indicates that the TADMUS DSS supports a goal; Partial indicates that the TADMUS DSS only partially supports a goal) (continued on next page)

Building Picture		*Coming on Watch Goals*
	✓	1 - Visualize external environment
	Partial	2 - Update own knowledge for coming watch from text msg information.
	✓	4 - Update understanding of threats
	Partial	9 - Comprehend briefing from outgoing ORO
		Background Goals
	Partial	Manage information from all sources coming into ORO position
	✓	4 - Build, monitor, maintain own awareness of pertinent surface environment
	✓	Build, monitor, maintain own awareness of pertinent air environment
	Partial	6 - Build, monitor, maintain own awareness of pertinent sub-surface environment
	Partial	7 - Build, monitor, maintain own awareness of integrated environment from above
	✓	8 - Switch attention between different tasks and re-acquire awareness quickly
		Threat Response Goals
	✓	1- Integrate new contact information with own global picture
	Partial	17 - Maintain own global awareness during threat response
	✓	20 - Check for other threats (i e , ensure OR checks)
	✓	24 - Regain own global awareness
Managing Response to Contact		*Threat Response Goals*
		5- Maximize number of information sources concerning contact
		6 - Optimize data quality for each information source
	✓	9 - Ensure contact classified correctly
	Partial	11- Ensure detailed and viable tactical plan prepared
		12 - Check warfare directors (WD) plan
	Partial	15 - Supervise execution of plan by OR team
	Partial	19 - Maneuver ship as required
	✓	21 - Respond to further threats (i.e., manage OR response)
	Partial	22 - Confirm enemy target destroyed

Table 6.1 - Categorization of ORO Goals (✓ indicates that the TADMUS DSS supports a goal; Partial indicates that the TADMUS DSS only partially supports a goal)

The review suggested that the TADMUS DSS was designed to support certain kinds of *activities* associated with the U.S. Navy TAO position. This role, although analogous to the Canadian Navy ORO position, seems to be concerned with managing anti-air contacts. It is unclear what, if any, team management or command responsibilities the TAO takes on in the U.S. Navy. Thus, it is important to note that areas in which the TADMUS DSS provide minimal support may reflect design decisions based on U.S. Navy organization.

As can be seen in Table 6.1, the TADMUS DSS does not provide very much support for four of the goal categories:

- Goals associated with team management;
- Goals associated with system and sensor management;
- Goals associated with management of ROE, orders, and legal limits; and
- Goals associated with communication (internal and external);

The TADMUS DSS generally provides only partial support to a few ORO goals within these categories. Although these areas of the ORO role are not well supported by the TADMUS DSS, this does not mean that the ORO is not supported in the actual operational environment. The ORO would have access to other forms of support under normal operational conditions. The Operations Room Supervisor (ORS), for example, is used by the ORO to assist in team management. The ORS monitors communication among members of the OR, resolves communication problems, passes information, and is generally available for special tasking by the ORO (Webb & McLean, 1997). The Combat System Engineer (CSE) is available to support system and sensor management. The ORO will have message files and manuals to deal with ROE, orders, and issues of authority. The Signal operators can assist with external communications. To assess the level of support actually

provided to OROs under real operational conditions, all support tools would have to be reviewed under realistic conditions.

In contrast to the preceding categories, the TADMUS DSS provides greater support to two goal categories:

- Goals associated with building the tactical picture; and
- Goals associated with managing the response to a contact.

In these cases, the TADMUS DSS generally provides full or partial support to the majority of ORO goals within these categories. These categories reflect the aspects of the ORO's role most closely associated with tactical operations. The high degree of support for these areas may reflect a greater emphasis on war-fighting by the TAO than the ORO position. Alternatively, it may reflect technological priorities of integrating sensor data and weapons capabilities over other functional areas.

The picture building goals identified by the CTA focused on the ORO's own picture and understanding of the situation. Presumably, however, the ORO's own picture will support his or her contribution to the integrated picture of the command team. Also, it is important to note that the TADMUS simulation reviewed for this report did not include any scenarios featuring subsurface contacts. The Geo Plot can present symbology for subsurface contacts but it is unclear to what extent the TADMUS DSS as a whole supports subsurface picture building. The TADMUS DSS was developed in the context of the U.S. Navy's AEGIS class, which serves primarily an anti-air role. This may have limited the extent to which the DSS can depict the subsurface environment and contacts.

6.4 Mental Representation Analysis

In addition to assessing which ORO goals are supported by the TADMUS DSS, a key issue is the level at which those goals are supported. Does the TADMUS DSS provide sufficient data, in an appropriate form, to permit the operator to build a useful mental representation for accomplishing his or her goals? This is not an easy question to answer but, as part of the analysis, the mental representation support provided by the TADMUS DSS was compared to the mental representation requirements suggested by the ORO goals.

Annex C contains a table listing all ORO goals from the CTA (Matthews et al., 1999; Matthews & Webb, 2000). Figure 6.2 below presents a sample of this table. Three sets of columns correspond to the three dimensions of mental representations identified in the CTA study. During the observation, the author recorded the mental representation support, in terms of each dimension, provided by the TADMUS DSS for each ORO goal. These assessments are listed for each goal under the columns marked "TADMUS." As described in Section 6.2, the author rated the kind of mental representations supported by the TADMUS DSS on the basis of the nature of the mental representation (i.e., the level of abstraction, level of focus, and domain of interest) an operator would likely create given the data and information available from the TADMUS DSS. In addition, judgments were based solely on the information provided by the TADMUS DSS, even if other sources of support would normally be available. Thus, in cases where the TADMUS DSS might support a concrete and specific representation, other forms of support (manuals, charts, etc.) could allow an ORO to develop a more abstract and global representation.

[redacted]						
1 - Visualize external environment						
2 - Update own knowledge for coming watch from text messages						
3 - Establish schedule of anticipated events for coming watch.						

Figure 6.2 - Sample of the Table Used to Compare Mental Representation Requirements to TADMUS DSS Support

After the data collection, the author evaluated the mental representation requirements of each ORO goal. This was done by judging the kind of mental representation minimally necessary to accomplish the goal. Again, this was a subjective assessment based on the author's understanding of the cognitive processes involved in performing ORO functions. Judgments were expressed in terms of the level of abstraction, level of focus, and domain of interest required by each goal. These assessments are listed in the table in Annex B next to the ratings of TADMUS support.

Inspection of Annex B provides insight into the level of support provided by the TADMUS DSS to any given ORO goal. Several trends emerged from this data, as follows:

1. None of the ORO goals identified in the CTA require a mental schema. A mental schema is a mental representation at the most abstract level of abstraction. It is generally thought of as a generic representation of a general class of situation or object rather than a representation of a specific situation or stimulus (Brewer & Nakamura, 1984; Thorndyke, 1984). Thus, it is not altogether surprising that the ORO goals do not require this kind of mental representation. The goals deal with the conduct of a watch and the management of events in that context. Consequently, the focus is on specific entities and events which are better represented in a mental model (see next point). Certainly the OROs' mental schemata will *inform* their mental models. That is, OROs will draw upon their extensive domain knowledge, which is likely organized in schemata, to interpret events and provide structure to their mental models. Their reasoning and decision making processes, however, will be performed with respect to specific mental models rather than the schemata themselves.[2]
2. Most ORO goals seem to require mental representations at the mental model or mostly abstract mental picture levels of abstraction. Few goals were judged to require a more concrete representation. The high degree of abstractness required reflects the integrative nature of the ORO's role; he or she must put together information from several sources, concerning all warfare areas, and relate the situation to pre-plans and ROE. Thus, a concrete mental picture, which provides a representation of data, is insufficient. Rather, the ORO needs a conceptual representation of the entities in surrounding environment and their functional inter-relations. A

[2] The distinction between a schema and mental model can be likened, in some respects, to the distinction between long-term and working memory (see Baddeley, 1990).

mental model provides a mental simulation of contacts, processes, and events that go beyond the raw data.

3. Although ORO goals generally require abstract mental representations, the TADMUS DSS tends to support mental representations at the mostly abstract and abstract/concrete mental picture levels of abstraction. Only rarely does the TADMUS DSS support representation at the mental model level. Thus, the TADMUS DSS tends to provide less than ideal support for OROs' mental representations. Even when the system supports a mostly abstract mental picture, the ORO goal tends to require a representation at the mental model level.

4. Most Coming on Watch and Background goals required representations with a global domain of interest. That is, they required the ORO to consider the integration of the surface, subsurface, and air warfare areas, as well as issues of ROE, non-military agencies in the area, navigation, team functioning, and so forth. These goals, of course, deal with preparation and management aspects of the ORO role. Threat-Related goals, not surprisingly, tended to require representations with a specific domain of interest because the ORO is dealing with a specific threat.

5. The TADMUS DSS tended to support mental representations with a specific domain of interest. Although the Geo Plot presents a spatial display of contacts (coded by type and class) and the CROs display information on a set of contacts, the TADMUS DSS essentially deals with one contact at a time. The most detailed information concerning a contact is available through the Track Summary and Track Profile modules, which display information only for the hooked contact. This means that the DSS presents only limited information concerning the relationships between contacts. Primarily, the Geo Plot and CROs provide spatial and kinematic information but no direct information concerning level of threat, possible intent, or capabilities. To assess the relative threat levels of several contacts or determine whether multiple contacts exhibit some common pattern of characteristics, the operator must cycle through the contacts, hooking each in turn to review detailed information and mentally integrating it.

6. The most difficult aspect of mental representations to assess was the level of focus. The ORO goals seem to require a flexible level of focus; i.e., a representation that permits the ORO to focus in on small portions of the environment but also focus out on an overview. The TADMUS DSS reflects this flexibility with a zoom feature for the Geo Plot, which changes the range scale. For the most part, the TADMUS DSS was rated as supporting a ranged-in level of focus because modules other than the Geo Plot have no range scale. Moreover, most modules deal with one contact at a time, biasing the display toward a single contact and a ranged-in focus.

These observations are illustrated in Figures 6.3 and 6.4 below. These figures display the mental representation requirements and mental representation support provided by the TADMUS DSS, categorized by level of abstraction, domain of interest, and level of focus. Figure 6.3 shows the number of goals requiring mental representations at each combination of the three dimensions. In cases where the goal was assessed to require representation at multiple levels of a dimension, the goal has been counted at both levels. As can be seen, many goals require global representations at the mental model level of abstraction. A fair number of goals (primarily those dealing with a specific contact) require specific representations at the Mostly Abstract and Concrete and Abstract levels.

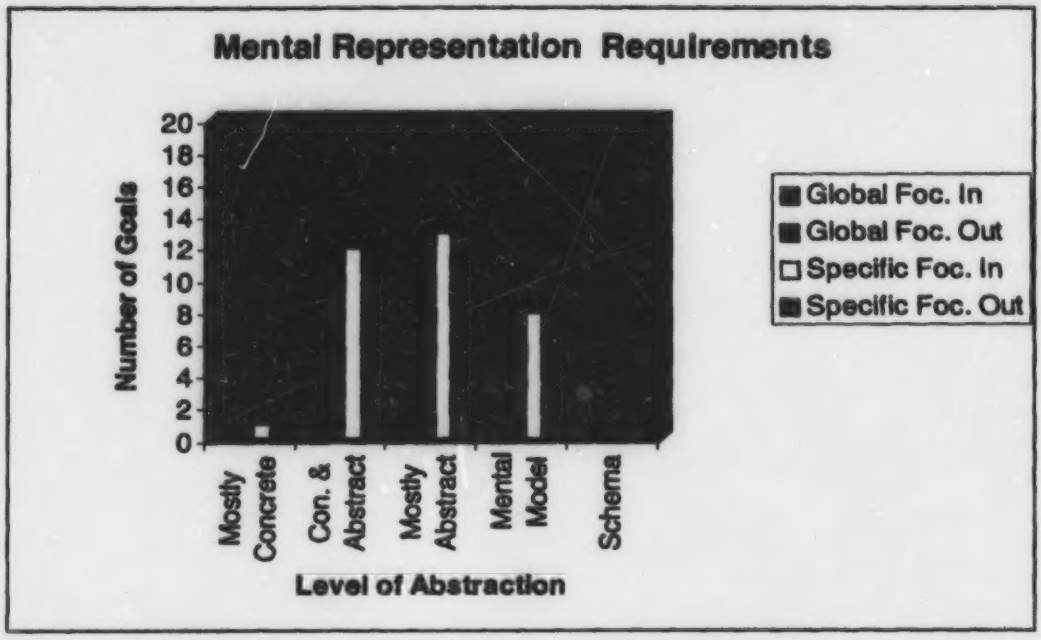

Figure 6.3 - Goal Mental Representation Requirements By Representation Dimension

Figure 6.3 shows the number of goals for which the TADMUS DSS provides support for mental representations at each combination of the three dimensions. As can be seen, the TADMUS DSS supports goals primarily at the specific and mostly abstract levels of representation. It is important to note that many of the goals supported at these levels require representations that are global and at the mental model level of abstraction.

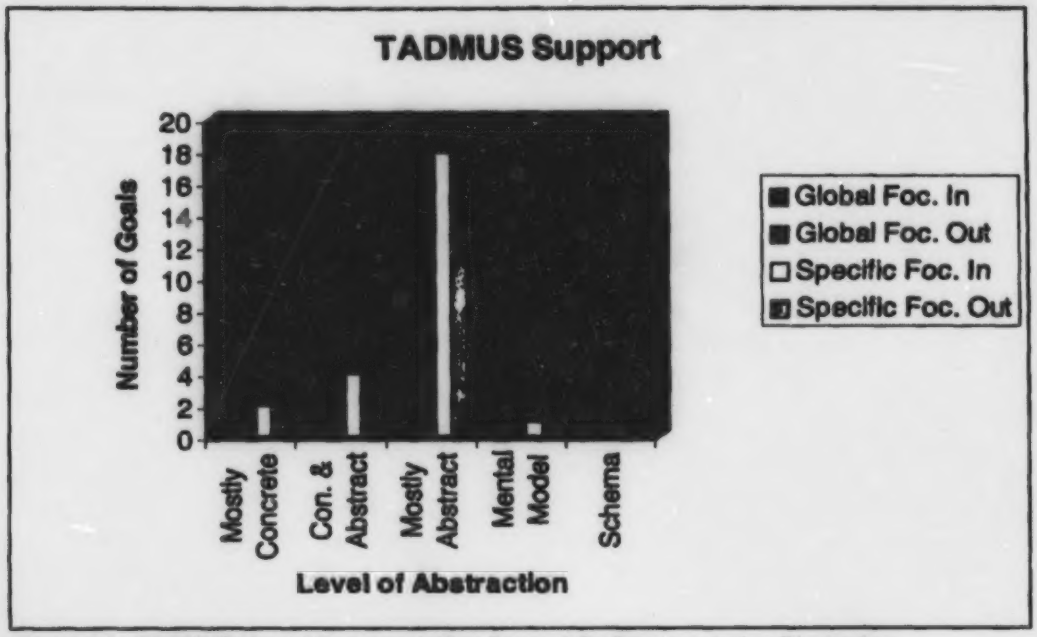

Figure 6.3 - TADMUS Mental Representation Support By Representation Dimension

6.5 Comparison to Abstraction Hierarchy

As part of their review of the TADMUS DSS, Bryant and Burns (2000) mapped the information content of the DSS onto the abstraction hierarchy created for the HALIFAX class frigate in Functional Information Profiles (FIP) diagrams (Burns & Bryant, 2000b). These diagrams displayed the areas of the HALIFAX class work domain supported by the TADMUS DSS (see Section 4.3). To relate the current review to that earlier one, FIP diagrams were created that displayed the ORO goal requirements mapped onto the HALIFAX class abstraction hierarchies. In this way, the diagrams display the areas of the work domain with which the ORO works; i.e., the areas of the work domain to which ORO goals pertain. Whereas the FIP diagrams from the Bryant and Burns (2000) report indicate the areas of the work domain for which the TADMUS DSS *provides* information, the FIP diagrams presented here can be viewed as delineating the areas of the work domain for which the ORO *needs* information.

Three FIP diagrams are presented below. The first illustrates the frigate (own ship) part of the work domain.

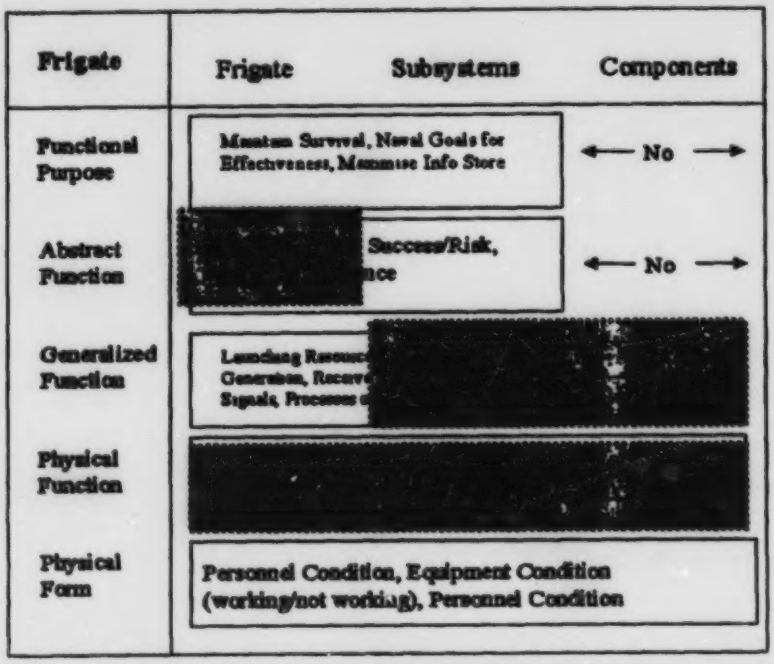

Figure 6.5 - FIP for the Frigate Domain (Shaded regions depict areas of the work domain for which the TADMUS DSS provides information)

The FIP diagram for the frigate domain makes clear that the ORO's goals address aspects of the work domain at every level of abstraction. Thus, OROs deal with everything from the physical condition of ship systems and the implications for ship functioning to the highest level purposes of the frigate. As can be seen from the shared regions in Figure 6.5, the TADMUS DSS provides information primarily at the physical function (capabilities) and generalized function (processes) levels. As a result, the TADMUS DSS does not support reasoning in terms of higher principles or purposes, with the exception of information pertaining to the risk level associated with contacts. The Basis for Assessment module provides an analysis of sensor data to help the operator classify potential threats. In addition, the Track Profile module maps potential threat weapon capabilities onto own ship weapon capabilities to assist in judging the threat level. Beyond these cases, however, it is up to the operator to assess a contact's possible intent and likely COA.

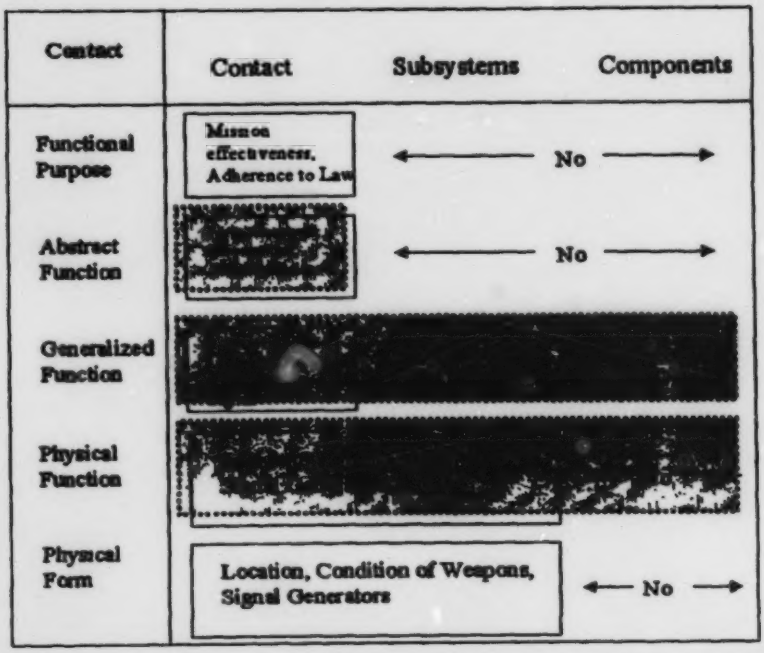

Figure 6.6 - FIP for the Contact Domain (Shaded regions depict areas of the work domain for which the TADMUS DSS provides information)

The FIP diagram for the contact domain (Figure 6.6) indicates that, as for the frigate domain, the ORO's goals address aspects of the work domain at every level of abstraction. In this case, however, ORO goals tend to deal with the contact as a whole, with less concern for subsystems and components of the contact. As for the frigate domain, the TADMUS DSS provides information primarily at the physical function (capabilities) and generalized function (processes) levels. In addition, however, the TADMUS DSS provides more support at the abstract function (first principles) level, primarily in terms of the Basis for Assessment module's analysis of the threat level and capabilities of the contact.

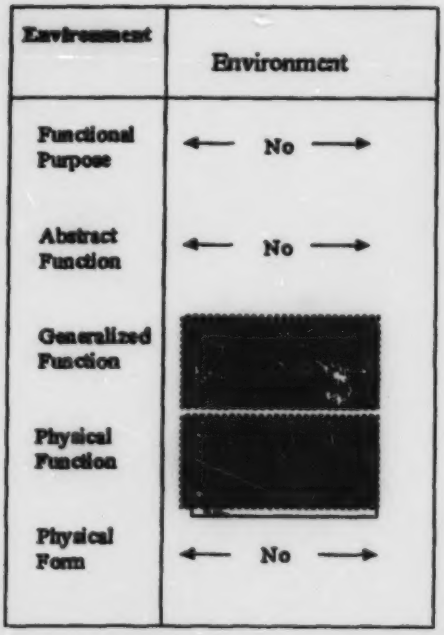

Figure 6.7 - FIP for the Environment Domain (Shaded regions depict areas of the work domain for which the TADMUS DSS provides information)

Figure 6.7 indicates that ORO goals create a need for environmental information at the physical function and generalized function levels of the work domain. These levels concern the physical processes and effects of the environment on the frigate and contacts. The TADMUS DSS provides information at both these levels but not as much as is needed. The TADMUS DSS omits a great deal of pertinent environmental information needed to understand how the environment will affect tactical operations, such as wind speed and direction, current forces, and the nature of temperature layers in the water.

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7 Conclusions and Recommendations

7.1 Conclusions

Although limited in scope, the review did reveal several broad trends in the correspondence of the TADMUS DSS to the goal and mental representation frameworks proposed by Matthews et al. (1999).

The TADMUS DSS provided support for only some classes of ORO goals, namely those associated with picture building and managing the response to a contact. These are critical areas of responsibility for the ORO but other classes of goals are at least as, if not more, important. Team management, in particular, may be the most important role of the ORO. Moreover, these classes (goals associated with team management, management of ROE/legal issues, system management, and communication) may not have adequate support. In judging the effectiveness of the TADMUS DSS, or any command and control system, attention must be paid to all areas of ORO responsibility within the context of all available support mechanisms.

Although the TADMUS DSS provides support to a number of key ORO goals, that support is not necessarily at an optimal level. The review of the mental representation requirements of ORO goals revealed that the TADMUS DSS generally supports mental representations that are less abstract than those needed. Many ORO goals, especially background and coming on watch goals, require mental models that integrate data with mission goals, ROE restrictions, and other conceptual issues. The TADMUS DSS, however, focuses on the immediate tactical situation and presents information that can help the operator build an abstract picture - but a picture that does not truly provide an integrated model of the situation.[3] In addition, the TADMUS DSS tends to support representations with a specific, rather than global, domain of interest because it presents detailed analysis of only one contact at a time. The system does not feature any analysis of the relations among multiple contacts. Nevertheless, an ORO needs to create a representation based on just that kind of relational knowledge in order to evaluate relative threats, priorities, and patterns that could suggest contacts' intent or possible COAs.

Overall, the TADMUS DSS is clearly a sophisticated system that offers a wide range of features to aid identification and classification of contacts and response to contacts. Moreover, some empirical evidence supports the DSS's usefulness, although independent evaluation is warranted. The current review, however, suggests that design of a DSS and workstation for the ORO position of the HALIFAX class would benefit from consideration of the goal and mental representation structures of OROs. By relating design concepts to goal and mental representation requirements, designers can better evaluate the appropriateness and value of those design concepts to supporting ORO performance.

[3] This is not a criticism of the TADMUS DSS; again, the system has been reviewed outside of an operational context in which other sources of support could support mental models for operators.

7.2 Limitations

Although the review reported here yielded results of interest, it bears repeating that there were several important limitations on that review that must be taken into account before attempting to generalize those results. First, the review was conducted over the course of one day and the TADMUS DSS simulation software had only a few scenarios with which to explore its functionality. It is not clear that the simulation reviewed provides a comprehensive overview of the TADMUS DSS concept. Furthermore, the simulation was "stand-alone" and provided no opportunity to examine how the workstation functioned as part of a system of workstations. This is a key issue because the system may have been designed to work with other support mechanisms. Thus, the lack of support for certain classes of goals and types of mental representations may reflect design decisions made in a broader context.

Finally, the TADMUS DSS was developed by and for the United States Navy, which has different strategic, tactical, and operational priorities than the Canadian Navy. It is likely, for example, that the TAO position does not have extensive subsurface warfare duties, whereas the ORO onboard the HALIFAX class frigate does. This limitation must be dealt with by identifying key departures of Canadian concerns from those of the United States and incorporating these in any future review of TADMUS systems.

7.3 Benefits of the Approach

This review applied a framework developed by Matthews et al. (1999) to describe the goals and mental representations employed by OROs in performing their role in the operation of the HALIFAX class frigate. Although the framework was developed as a descriptive model of ORO functioning, there are a number of benefits to using the framework to analyse a system

First, the framework provides a means of evaluation that is easy to do, fast, and relatively inexpensive. The review of the TADMUS DSS was completed in one day with minimal resources and, although it could be extended in several ways, the analysis revealed useful findings. Second, the framework can be applied to any type of system. Because the framework relates to the ORO's mental representations, it pertains to any system or tool that might provide support to OROs. The current review has demonstrated that it is possible to assess the level of support to ORO goals and mental representations provided by a system.

A third benefit of the framework is that it can provide comparative data if an analysis is performed on multiple systems or versions of a system. In this case, the kinds and levels of support to ORO goals and mental representations can be evaluated independently and compared to provide a detailed evaluation of which system provides greater support in specific areas.

The main benefit of the framework is that it can be used to identify, at a broad level, the areas of the ORO's responsibilities that are supported and those that are not. In addition, the framework allows one assess the degree to which the level of support meets the ORO's needs in terms of mental representation. Thus, the analysis can serve as a first step in judging what areas of the ORO role need further support and what specific forms of support may best fit ORO needs.

7.4 Recommendations

There seem to be two tracks to following up on this work. One is to delve more deeply into the issues raised by validating the results with naval SMEs. The SMEs could be used to judge the

mental representation requirements of the ORO goals and ensure that the analysis is accurate. The SMEs could also provide validation of the levels to which the TADMUS DSS and the current HALIFAX CCS support those mental representation needs. This effort would be valuable only if one believes that the approach employed in this report can be used to develop design guidelines.

Another way to follow up on the work would be to use the analysis technique as a tool in rapid prototyping of CCS concepts. In this case, one could perform the same sort of fast review for the current HALIFAX CCS and versions of CCS concepts. The goal would be to quickly obtain an estimate of the extent to which these systems support the ORO position and identify areas for development. In this case, the validity of the analysis would not be a major concern because the goal is to use the analysis as just a starting point and independent validation would be done of any system prototype developed.

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Annex A

To: "Review of the TADMUS Decision Support System"

Summaries of the Information Content of the TADMUS DSS Modules

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This annex contains summaries of the information content of each module of the TADMUS DSS. These summaries were derived from the data collected during the one-day review of the TADMUS DSS.

Module	Information Content
Geo Plot	• Shows the physical environment: land and sea areas. • Shows the location of own ship and contacts plus: • Headers to indicate course and bearing • Speed indicated by rate of movement (velocity leaders). • Shows air lanes (option) • Shows weapon ranges (self and contact) (optional) • Own movement must be inferred by relative changes in the relative positions of land forms to own ship (ship-centered map).
Mini-Character Read Outs	• Summarizes the 16 highest priority tracks (based on output of the Basis for Assessment module). • Classification (threat, unknown, friendly) or specific identification if possible (e.g., ship name, type of aircraft, etc.). • Bearing and range from own ship. • Altitude. • Sensor type being emitted. • IFF status (on or off) • Alerts in pop-up box.
Track Summary	• Shows: • Track ID. • Assessment (judgment of DSS). • Status (immediate etc.) • Bearing. • Course. • Range. • Speed. • Altitude. • Closest Point of Approach • Historical data on bearing, speed, course, and altitude (e.g., "bearing constant," "altitude increasing," etc.). • Intelligence (indication of potential actions based on correlating track with intelligence data). • EW status (emitter type). • IFF status (on or off). • Last alert. • Age of contact (how long it has been recorded by the system).
Track Profile with Aspect Inset	• Shows plot of altitude versus range for selected air tracks or plot of range only for surface contacts: • Track plotted by its range and altitude or range only (surface). • Contact weapon envelope – plot of ranges and altitudes at which presumed weapon can be fired at own ship.

	• Own ship weapon envelope - plot of ranges and altitudes at which selected weapon can be fired at contact. • Track history (record of altitude by range of contact). • Aspect Inset permits assessments of ship positioning to deal with selected contact.
Response Manager	• Shows the list of actions that can be taken plotted against the range of the selected contact. • Indicates the selected contact's current range. • Highlights actions that have already been taken (gray-out selected actions). • Indicates whether contact closing or opening.
Basis for Assessment	• Presents the DSS's interpretation of available sensor data: • Evidence for and against contact being a threat (i.e., what sensor data and inferences about contact behavior, identity, and capabilities are consistent with it being a threat). • Evidence for contact being an unknown. • Evidence for contact being a friendly. • Presents the list of necessary assumptions for a classification to be true (i.e., aspects of the contact's physical state, course, radar on/off, etc., and its intent).

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Annex B

To: "Review of the TADMUS Decision Support System"

TADMUS DSS Workstation Review Data

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This annex contains transcribed copies of the data collected during the one-day review of the TADMUS DSS. The observations were made by the author on February 12, 2001 when he reviewed the TADMUS Project Decision Support System (DSS-II) Version 4.6.

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TADMUS Review Datasheet: Foreground (Threat Response) Goals

CTA Goal	Present?	Comments (links)	Mental Representation		Comments
1 - Visualize external environment	Yes	No data on ship systems. Geo Plot shows coastline, contacts, topology, nav chart, histories, course leaders, weapon ranges, air lanes Track Summary, CROs show detailed contact information	Abstractness	Level of Focus	Can zoom in by selecting range on Geo Plot View itself gives physical environment and nature of contacts; not itself enough for mental model (e g., no intent)
			Most Concrete		
			Concrete/Abstract		
				Domain - Interest	
			Mental Model		
			Mental Schema	Specific	
2 - Update own knowledge for coming watch from text msg information.	Partial	Track Summary and CROs: - pop-up menus to read alerts for each contact - does not cover all message traffic - deals only with tactical data	Abstractness	Level of Focus	Alerts provide info about threat status and behavior of contacts Refers to abstract picture of contacts, including intent of contact
			Most Concrete		
			Concrete/Abstract	Ranged out	
				Domain - Interest	
			Mental Model	Global	
			Mental Schema		
3 - Establish schedule of anticipated events for watch.	No		Abstractness	Level of Focus	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	
4 - Update understanding of threats	Yes	Track Summary and CRO: Contact info, detailed Track Profile & Response Manager: - Indicate weapon ranges of contact vs. own ship - Provide list of responses with range/time indicator *What it can do to me & what I can do to it* Basis for Assessment - eval of degree of threat + evidence	Abstractness	Level of Focus	Primarily ranged-in, specific view Operator has to mentally integrate all contacts and threat info to create mental model of current situation (e.g , priorities) CROs organized by DSS assessment of threat; provides some global view of situation
			Most Concrete		
			Concrete/Abstract	Ranged out	
				Domain - Interest	
			Mental Model	Global	
			Mental Schema		

TADMUS Review Datasheet: Foreground (Threat Response) Goals

CTA Goal	Present?	Comments (links)	Mental Representation		Comments
5 - Establish current activity and work focus among OR teams	Partial	CROs, Track Summary, Track Profile, Basis for Assessment By reviewing info on contacts, operator can determine priorities (e.g., AAW) But no specific tool for setting priorities or planning responses to multiple contacts	Abstractness Most Concrete Concrete/Abstract [redacted] Mental Model Mental Schema	Level of Focus [redacted] Ranged out Domain - Interest Global [redacted]	
6 - Establish required action items during watch	Partial	Geo Plot, Track Summary, CROs, Track Profile, Basis for Assessment, Response Manager. Use these modules to get data to determine some actions; i.e., how to respond to selected contacts	Abstractness Most Concrete Concrete/Abstract [redacted] Mental Model Mental Schema	Level of Focus [redacted] Ranged out Domain - Interest Global [redacted]	Data from modules is generally specific to a selected contact Provides somewhat abstract picture that incorporates contact identity and behavior Operator must assemble mental model and global picture
7 - Review OR system performance (sensors, etc) and rectify/ work around	No	No modules provide indication of sensor/system functioning	Abstractness Most Concrete Concrete/Abstract Mostly Abstract Mental Model Mental Schema	Level of Focus Ranged in Ranged out Domain - Interest Global Specific	
8 - Comprehend items in CO's order book	No	No modules refer to CO order book or other sets of orders	Abstractness Most Concrete Concrete/Abstract Mostly Abstract Mental Model Mental Schema	Level of Focus Ranged in Ranged out Domain - Interest Global Specific	

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TADMUS Review Datasheet: Foreground (Threat Response) Goals

CTA Goal	Present?	Comments (links)	Mental Representation		Comments
9 - Comprehend briefing from outgoing ORO	Partial	No specific log or tool for outgoing operator to inform incoming ORO All modules contribute to understanding situation; provide data that could be used to understand a brief	**Abstractness**	**Level of Focus**	Data from modules ranges from concrete to abstract (e.g , Basis for Assessment) Operator must assemble global pictiure Data key to understanding current situation
			Most Concrete	Ranged in	
			Concrete/Abstract	[redacted]	
			[redacted]	**Domain - Interest**	
			Mental Model	Global	
			Mental Schema	[redacted]	
10 - Optimize own CCS	Partial	Can configure Geo Plot range scale, background info, overlays (air lanes, course leaders, etc.) No controls for sensor settings but modules provide data on threats (EW emitter, likely weapon) This data could be used to set optimal sensor and EW settings	**Abstractness**	**Level of Focus**	Info deals with specific contacts; operator must integrate to create global picture to determine what is best CCS settings for current set of contacts
			Most Concrete	[redacted]	
			Concrete/Abstract	Ranged out	
			[redacted]	**Domain - Interest**	
			Mental Model	Global	
			Mental Schema	[redacted]	
11 - Focus OR team on issues for coming watch	No		**Abstractness**	**Level of Focus**	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	**Domain - Interest**	
			Mental Model	Global	
			Mental Schema	Specific	
12 - Establish command presence	No		**Abstractness**	**Level of Focus**	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	**Domain - Interest**	
			Mental Model	Global	
			Mental Schema	Specific	

C2 A Goal	Present?	Comments (links)	Mental Representation		Comments
13 - Review pertinent pre-plans, procedures, and ROE for coming watch	Partial	Response Manager lists possible actions for responding to contacts ordered by level of severity/force Provides a general response plan (pre-plan) Unclear whether this module captures the flexibility of pre-plans; i.e., tailoring responses to different sorts of threats	Abstractness	Level of Focus	Response Manager deals with one contact at a time Lists specific actions to be taken
			Most Concrete		
			Concrete/Abstract	Ranged out	
				Domain - Interest	
			Mental Model	Global	
			Mental Schema		

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[redacted]	Predict[redacted]	[redacted] (links)	[redacted]		Comments
1 - Monitor and manage the OR team	No		Abstractness	Level of Focus	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	
[redacted]Manage information from all sources coming into ORO position	Partial	Modules present sensor data only Access to database info to interpret sensor data through Basis for Assessment (lists evidence) Other info (intel, messages, etc) not integrated in DSS	Abstractness	Level of Focus	Sensor data provides fairly concrete picture Basis for Assessment uses a database to interpret sensor data, this presents a picture that is abstract, tending toward mental model But much info needed to understand situation and DSS covers only one aspect of info management
			Most Concrete	[redacted]	
			[redacted]		
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	[redacted]	
3 - Monitor and manage OR equipment capability	No		Abstractness	Level of Focus	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	
4 - Build, monitor, maintain own awareness of pertinent surface environment	Yes	Geo Plot, CROs, Track Summary, Track Profile: geographic data and data on contacts Basis for Assessment provides detailed info for eval of contact	Abstractness	Level of Focus	Have to mentally integrate to build global picture
			Most Concrete	[redacted]	
			Concrete/Abstract		
			[redacted]	Domain - Interest	
			Mental Model	Global	
			Mental Schema	[redacted]	

TADMUS Review Datasheet: Foreground (Threat Response) Goals

CTA Goal	Present?	Comments (Info)	Mental Representation		Comments
5 - Build, monitor, maintain own awareness of pertinent air environment	Yes	Geo Plot, CROs, Track Summary, Track Profile: geographic data and data on contacts Basis for Assessment provides detailed info for eval of contact	Abstractness Most Concrete Concrete/Abstract [redacted] Mental Model Mental Schema	Level of Focus [redacted] Domain - Interest Global [redacted]	Have to mentally integrate to build global picture
6 - Build, monitor, maintain own awareness of pertinent sub-surface environment	Partial	DSS can present info about subsurface contacts but was designed for AEGIS, primarily AAW role Unclear what underwater capabilities DSS has because scenarios involved no subsurface contacts Presumably UWW could be integrated in DSS to same extent as surface and air	Abstractness Most Concrete Concrete/Abstract [redacted] Mental Model Mental Schema	Level of Focus [redacted] Domain - Interest Global [redacted]	
7 - Build, monitor, maintain own awareness of integrated environment from above	Partial	Modules provide extensive data Track Profile integrates aspects of contact and ship to indicate risk Basis for Assessment uses database to eval threat	Abstractness Most Concrete Concrete/Abstract [redacted] Mental Model Mental Schema	Level of Focus [redacted] Domain - Interest Global [redacted]	Modules do little to integrate multiple contacts Operator must mentally integrate to discern patterns, relation to mission goals
8 - Switch attention between different tasks and re-acquire awareness quickly	Yes	Easy to change range in, range out for Geo Plot, Geo Plot also change overlays to highlight relevant aspects of env., Easy to switch between different contacts and update on position, alt, EW, etc Using Track Profile, can switch between contacts on basis of threat level, what action to take toward contact Use Track Profile and CROs to prioritize threats (can't rely on CROs alone); determine when have to take action for each threat	Abstractness Most Concrete Concrete/Abstract Mostly Abstract [redacted] Mental Schema	Level of Focus [redacted] Domain - Interest Global [redacted]	Lack of integration of multiple threats, limits model of situation; requires mental work by operator Only CROs provide indication of relative threat of mult. Threats by rank ordering them on basis of DSS eval. No plot of capabilities of multiple threats

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CTA Goal	Present?	Comments (links)	Mental Representation		Comments
9 - Maintain awareness of ORO's authority to act	No	Only Alerts indicate when contact is within ROE limit No indication of what operator can do, cannot do on basis of ROE, standing orders, CO's battle doctrine, etc. Basis for Assessment uses ROE limit in eval of threats	Abstractness	Level of Focus	ROE info probably committed to memory by ORO but ORO must mentally evaluate contact with respect to ROE; no display aid
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	
10 - Check outgoing message traffic (text, voice)	No	No data concerning out-going messages Only Response Manager refers to warnings that can be issued to contact	Abstractness	Level of Focus	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	

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GTA Goal	Present?	Comments (links)	Mental Representation		Comments
1 - Integrate new contact information with own global picture	Yes	Track Summary, CROs' Data on contact Basis for Assessment, Track Profile: Eval of threat Geo Plot: Spatial relation to own ship and other contacts, track history, leaders, etc.	Abstractness	Level of Focus	No salient alert when new contact appears Provides data about new contact; operator must integrate with other contacts and mission goals
			Most Concrete		
			Concrete/Abstract	Ranged out	
				Domain - Interest	
			Mental Model	Global	
			Mental Schema		
2 - Ensure OR prepares quick first response, broad plan for worst case	Partial	Response Manager lays out general sequence of actions for dealing with contact No planning tool that allows operator to generate own action sequence No customized pre-plans	Abstractness	Level of Focus	Up to operator to select actions suited to contact Deal with one contact at a time; no indication of whether other contacts more urgent No indication of how actions affect other contacts
			Most Concrete		
			Concrete/Abstract	Ranged out	
				Domain - Interest	
			Mental Model	Global	
			Mental Schema		
3 - Optimize work among OR team(s)	No	Modules do not deal with other positions and their responsibilities	Abstractness	Level of Focus	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	
4 –Optimize information flow within and outside OR	No	No modules deal with communication within or outside OR Response Manager has actions for warning contact, reporting to senior (actions apparently taken automatically)	Abstractness	Level of Focus	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	

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CTA Goal	Present?	Comments (links)	Mental Representation		Comments
5 - Maximize number of information sources concerning contact	No	No way to add additional data sources When contact is selected, have access to all available sensor, EW data	Abstractness	Level of Focus	Could be a limitation of simulation
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	
6 - Optimize data quality for each information source	No	As above	Abstractness	Level of Focus	As above
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	
7 - Establish communication with contact to resolve identity and intentions	No	Response Manager contains action to warn contact but module does not allow communication	Abstractness	Level of Focus	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	
8 - Conduct warnings in accordance with TG tasking	Yes	Response Manager contains action to warn contact Provides 3 levels of warnings plus warning actions (warning shot, illuminating, etc.) Use Track Profile, Track Summary, Basis for Assessment to determine threat and hence appropriate warning	Abstractness	Level of Focus	
			Most Concrete	[redacted]	
			[redacted]	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	[redacted]	

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GTA Goal	Present?	Contents (links)	Mental Representation		Comments
9 - Ensure contact classified correctly	Yes	Track Summary, CROs: sensor, EW data Basis for Assessment: Use database to interpret data & present likely classification Track Profile: relation of contact movement & weapon to own ship	Abstractness	Level of Focus	
			Most Concrete		
			Concrete/Abstract	Ranged out	
				Domain - Interest	
			Mental Model	Global	
			Mental Schema		
10 - Ensure OR detects missile firing and establish firm radar track	Partial	Track Summary, CROs: Sensor data lead to track for missile No means to direct OR to attend to or act on missile threat	Abstractness	Level of Focus	Simulation scenarios do not involve weapons launch by contacts; thus, observations are speculative
			Most Concrete		
			Concrete/Abstract	Ranged out	
				Domain - Interest	
			Mental Model	Global	
			Mental Schema		
11- Ensure detailed and viable tactical plan prepared	Partial	Response Manager: implement pre-plan But don't know how detailed or viable plan is Aspect Inset: indicate whether need to maneuver to allow engagement	Abstractness	Level of Focus	Simulation scenarios do not involve weapons launch by contacts; thus, observations are speculative
			Most Concrete		
			Concrete/Abstract	Ranged out	
				Domain - Interest	
			Mental Model	Global	
			Mental Schema		
12 - Check warfare directors (WD) plan	No	No modules for interacting with other positions	Abstractness	Level of Focus	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	

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GTA Goal	Present?	Comments (links)	Mental Representation		Comments
13 - Make CO aware of all relevant components of the plan. Get feedback from CO	No		Abstractness	Level of Focus	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	
14 - Ensure all OR team aware of plan. Emphasize key points	No		Abstractness	Level of Focus	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	
15 - Supervise execution of plan by OR team	Partial	Response Manager provides operator with control over execution of actions	Abstractness	Level of Focus	Unclear how Response Manager works; i.e., whether instructions are carried out by system or whether given to subordinates
			Most Concrete		
				Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema		
16 –Ensure standard procedures completed correctly (ZIPPO, AIR RED, Action Stations, Greyhound, etc)	No	No feedback on whether actions implemented correctly Geo Plot will no longer show a contact that has been destroyed but there is no alarm or display feature that indicates destruction of contact	Abstractness	Level of Focus	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	

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CTA Goal	Present?	Comments (links)	Mental Representation		Comments
17 - Maintain own global awareness during threat response	Partial	Track Summary, CROs provide data on each contact Track Profile relates each contact to own ship in terms of capabilities Basis for Assessment evaluates threat level of selected contact Geo Plot: spatial relations among all contacts	**Abstractness** Most Concrete Concrete/Abstract [redacted] Mental Model Mental Schema	**Level of Focus** [redacted] **Domain - Interest** Global [redacted]	Data from modules is necessary but not sufficient to stay on top of global picture Missing: mission goals, plan, ROE, correlations among contacts Operator must integrate info on contacts and relate to mission goals
18 - Back up Warfare Director (WD) as required	No		**Abstractness** Most Concrete Concrete/Abstract Mostly Abstract Mental Model Mental Schema	**Level of Focus** Ranged in Ranged out **Domain - Interest** Global Specific	
19 - Maneuver ship as required	Partial	Aspect Inset: indicates necessary maneuver to respond to selected contact with selected weapon But no means to control maneuver No relation to mission goals	**Abstractness** Most Concrete [redacted] Mostly Abstract Mental Model Mental Schema	**Level of Focus** [redacted] Ranged out **Domain - Interest** Global [redacted]	Provides indication of needed maneuver only for case of responding to a threat No indication of how to maneuver to deploy chaff effectively (may be limitation of simulation)
20 - Check for other threats (i.e., ensure OR checks)	Yes	CROs rank order threats making it easy to select each in turn and eval level of threat using Track Profile & Basis for Assessment DSS automatically eval whether contact is threat, friend, unknown; displays class by symbology and colour in Geo Plot (can relate to other threats)	**Abstractness** Most Concrete Concrete/Abstract [redacted] Mental Model Mental Schema	**Level of Focus** [redacted] **Domain - Interest** Global [redacted]	By selecting track, have access to detailed info through Track Summary, Track Profile, and Basis for Assessment

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CTA Goal	Present?	Comments (links)	Mental Representation		Comments
21 - Respond to further threats (i.e., manage OR response)	Yes	CROs: select threat Track Summary: contact data Track Profile, Basis for Assessment: appropriate action Response Manager: select action	Abstractness	Level of Focus	Deal with one contact at a time Hard to see relationships among contacts, expect spatial relations in Geo Plot and kind of platform in CROs
			Most Concrete		
			Concrete/Abstract		
				Domain - Interest	
			Mental Model	Global	
			Mental Schema		
22 - Confirm enemy target destroyed	Partial	Contact disappears from Geo Plot and other modules if destroyed No specific indicator of what happened No alert or display to indicate successful engagement	Abstractness	Level of Focus	Only indication is change in display; i.e., contact disappears from Geo Plot, CROs
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema		
23- Assess implications of damage to own ship from missile (etc) hit	No		Abstractness	Level of Focus	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	
24 - Regain own global awareness	Yes	Cycle through contacts; inspect contact data, threat eval by DSS	Abstractness	Level of Focus	Operator has to integrate the contacts into mental model of situation
			Most Concrete		
			Concrete/Abstract	Ranged out	
				Domain - Interest	
			Mental Model	Global	
			Mental Schema		

TADMUS Review Datasheet: Foreground (Threat Response) Goals

CTA Goal	Present?	Comments (links)	Mental Representation		Comments
25- Re-focus OR team. Re establish command presence	No		Abstractness	Level of Focus	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	
26 –Stand down weapons	No	Response Manager has no actions to control status of weapons (i.e , active, not active)	Abstractness	Level of Focus	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	
27 - Stand down ship	No		Abstractness	Level of Focus	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	
28 Complete and send reports	No		Abstractness	Level of Focus	
			Most Concrete	Ranged in	
			Concrete/Abstract	Ranged out	
			Mostly Abstract	Domain - Interest	
			Mental Model	Global	
			Mental Schema	Specific	

Annex C

To: "Review of the TADMUS Decision Support System"

Comparison of Mental Representation Requirements to the Level of Support Provided by the TADMUS DSS

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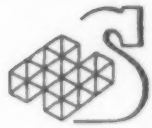

This annex contains a comparison table listing all ORO goals from the CTA (Matthews et al., 1999; Matthews & Webb, 2000). Three sets of columns correspond to the three dimensions of mental representations identified in the CTA study. During the observation, the author recorded the mental representation support, in terms of each dimension, provided by the TADMUS DSS for each ORO goal (see Section 6.2). These assessments are listed for each goal under the columns marked "TADMUS." After the data collection, the author evaluated the mental representation requirements of each ORO goal. This was done by judging the kind of mental representation minimally necessary to accomplish the goal. Again, this was a subjective assessment based on the author's understanding of the cognitive processes involved in performing ORO functions. Judgments were expressed in terms of the level of abstraction, level of focus, and domain of interest required by each goal. These assessments are listed in the columns next to the ratings of TADMUS support.

The table allows comparison of the extent to which TADMUS DSS support for mental representations meets ORO mental representation requirements. The results of this analysis are discussed in Section 6.4.

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[redacted]						TADMUS
1 - Visualize external environment	Mostly Abstract	Mostly Abstract (but TADMUS provides less info than needed; this is true in many cases)	In & Out	In & Out	Global	Global
2 - Update own knowledge for coming watch from text messages	Mental Model	Mostly Abstract	In & Out	In	Global	Specific
3 - Establish schedule of anticipated events for coming watch	Mental Model	[redacted]	In & Out	[redacted]	Global	[redacted]
4 - Update understanding of threats	Mental Model (e.g., prioritize all potential threats)	Mostly Abstract	In & Out	In	Global	Specific
5 - Establish current activity levels and work focus among OR teams	Mental Model	Mostly Abstract	In & Out	In	Global	Specific
6 - Establish required action items during watch	Mostly Abstract	Mostly Abstract	In & Out	In	Specific	Specific
7 - Review OR system performance (sensors, etc) and rectify / work around	Concrete	[redacted]	In	[redacted]	Specific	[redacted]
8 - Comprehend items in CO's order book	Mental Model (e.g., relate to ROE, threats, etc.)		In & Out		Global	
9 - Comprehend briefing from outgoing ORO	Mental Model	Mostly Abstract	In & Out	In & Out	Global	Specific
10 - Optimize own CCS	Mental Model (Settings depend on situation and info gathering strategies)	Mostly Abstract	In & Out	In	Global & Specific	Specific
11 - Focus OR team on issues for coming watch	Mostly Abstract	[redacted]	In	[redacted]		[redacted]
12 - Establish command presence	Mostly Abstract		In		Specific	
13 - Review pertinent pre-plans, procedures and ROE for coming watch	Mental Model	Concrete & Abstract	In & Out	In	Global	Specific

ORO						
Background Goals						
1 - Monitor and manage the OR team	Concrete & Abstract		In			
2 - Manage information from all sources coming into ORO position (speech, text, other)	Mental Model	Concrete & Abstract	In & Out	In & Out	Global	Specific
3 - Monitor and manage OR equipment capability	Mostly Abstract		In & Out		Specific	
4 - Build, monitor, and maintain awareness of pertinent surface environment	Mental Model	Mostly Abstract	In & Out	In & Out	Global	Specific
5 - Build, monitor, and maintain awareness of pertinent air environment	Mental Model	Mostly Abstract	In & Out	In & Out	Global	Specific
6 - Build, monitor, and maintain awareness of pertinent sub-surface environment	Mental Model	Mostly Abstract	In & Out	In & Out	Global	Specific
7 - Build, monitor, and maintain awareness of integrated environment from above	Mental Model	Mostly Abstract	In & Out	In & Out	Global	Specific
8 - Switch attention between different tasks and re-acquire awareness quickly	Mental Model	Mostly Abstract	In & Out	In & Out	Global	Specific
9 - Maintain awareness of ORO's authority to act	Mental Model		In & Out		Global	
10 - Check outgoing message traffic (text, voice)	Mostly Abstract		In		Specific	
Threat Response Goals						
1 - Integrate new contact information with global awareness picture	Mental Model	Mostly Abstract	In & Out	In	Global & Specific (Must focus on threat but always relate it to the global situation, including other threats, responsibility to TG, etc.)	Specific
2 - Ensure OR prepares quick first response, broad plan for worst case	Mental Model	Mostly Abstract	In & Out	In	Global & Specific	Specific
3 - Optimize work among OR team(s)	Mostly Abstract		In		Specific	
4 - Optimize information flow	Mostly		In		Specific	

within and outside OR	Abstract					
5 - Maximize number of information sources concerning contact	Concrete & Abstract		In		Specific	
6 - Optimize data quality for each information source	Concrete & Abstract		In		Specific	
7 - Establish communication with contact to resolve identity and intentions	Concrete & Abstract		In		Specific	
8 - Conduct warnings in accordance with TG tasking	Mostly Abstract	Concrete & Abstract	In	In	Specific	Specific
9 - Ensure contact classified correctly	Mental Model	Mostly Abstract	In	In	Specific	Specific
10 - Ensure OR detects missile (etc.) and establish firm track	Concrete & Abstract	Mostly Abstract	In	In	Specific	Specific
11 - Ensure detailed and viable tactical plan prepared	Mental Model	Mostly Abstract	In	In	Specific	Specific
12 - Check warfare director (WD) plan	Mental Model (Evaluating plan requires mental model)		In		Specific	
13 - Make CO aware of relevant components of plan. Get feedback from CO	Mental Model		In		Specific	
14 - Ensure all OR team aware of plan. Emphasize key points	Concrete & Abstract		In		Specific	
15 - Supervise execution of plan by OR team	Concrete & Abstract	Concrete & Abstract	In	In	Specific	Specific
16 - Ensure standard procedures completed correctly (ZIPPO, etc.)	Concrete & Abstract		In		Specific	
17 - Maintain own global awareness during threat response	Mental Model	Mostly Abstract	In & Out	In & Out	Global	Specific
18 - Back up Warfare Directors (WD) as required	Concrete & Abstract		In		Specific	
19 - Maneuver ship as required	Mostly Abstract (Abstract picture of ship movement needed)	Concrete & Abstract	In	In	Specific	Specific
20 - Check for other threats	Mental Model	Mostly Abstract	In & Out	In & Out	Global	Specific

ORO Goal						
21 - Respond to further threats	Concrete & Abstract to Mental Model (Encompasses set of previous goals)	Mostly Abstract	In & Out	In & Out	Specific	Specific
22 - Confirm enemy target destroyed	Concrete & Abstract	Mostly Concrete	In	In	Specific	Specific
23 - Assess implications of damage to own ship from missile (etc) hit	Mostly Abstract		In		Specific	
24 - Regain own global awareness	Mental Model	Mostly Abstract	In & Out	In & Out	Global	Specific
25 - Re-focus OR team Re establish command presence	Mostly Abstract		In		Specific	
26 - Stand down own weapons	Concrete & Abstract		In		Specific	
27 - Stand down ship	Concrete & Abstract		In		Specific	
28 - Complete and send reports	Mostly Abstract		In		Specific	

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14. ABSTRACT

(U) This report describes a review of the U.S. Navy TADMUS Decision Support System (DSS) with respect to the goal and mental representation requirements of the Operations Room Officer (ORO) position of the HALIFAX class frigate. The review was conducted in a one-day session on February 12, 2001, using TADMUS DSS simulation software provided by DCIEM. The goal and mental representation frameworks were based on an analysis of results of a Cognitive Task Analysis (CTA) for the ORO position by Matthews, Webb, and Bryant (1999). The goal of the review was to identify which dimensions of ORO mental representations and which ORO goals are supported by the U.S. Navy TADMUS DSS and which dimensions are not supported. The review indicated that the TADMUS DSS supported only some ORO goals and generally did not support as abstract a level of mental representation as needed by OROs.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) Human Factors Engineering
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Cognitive Task Analysis

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